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EPHEMERIS DATA AND ERROR ANALYSIS IN SUPPORT OF A COMET ENCKE INTERCEPT MISSION

Prepared for
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ABSTRACT

Utilizing an orbit determination based upon 65 observations over the 1961 - 1973 interval, ephemeris data were generated for the 1976-77, 1980-81 and 1983-84 apparitions of short period comet Encke. For the 1980-81 apparition, results from a statistical error analysis are outlined. All ephemeris and error analysis computations include the effects of planetary perturbations as well as the non-gravitational accelerations introduced by the outgassing cometary nucleus. In 1980, excellent observing conditions and a close approach of comet Encke to the earth permit relatively small uncertainties in the cometary position errors and provide an excellent opportunity for a close flyby of a physically interesting comet.

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1. INTRODUCTION

The Comets and Asteroids Scientific Working Group, working in an advisory capacity to NASA, has recently recommended that the 1980 apparition of comet Encke be considered the principal target of opportunity for a space probe to a comet. Comet Encke has been selected as the prime target because

1. It has been observed at more apparitions than any other comet
2. Its orbit is considered well known and predictable
3. It passes within 0.3 a.u. of the Earth in 1980, and
4. It is still a reasonably active comet.

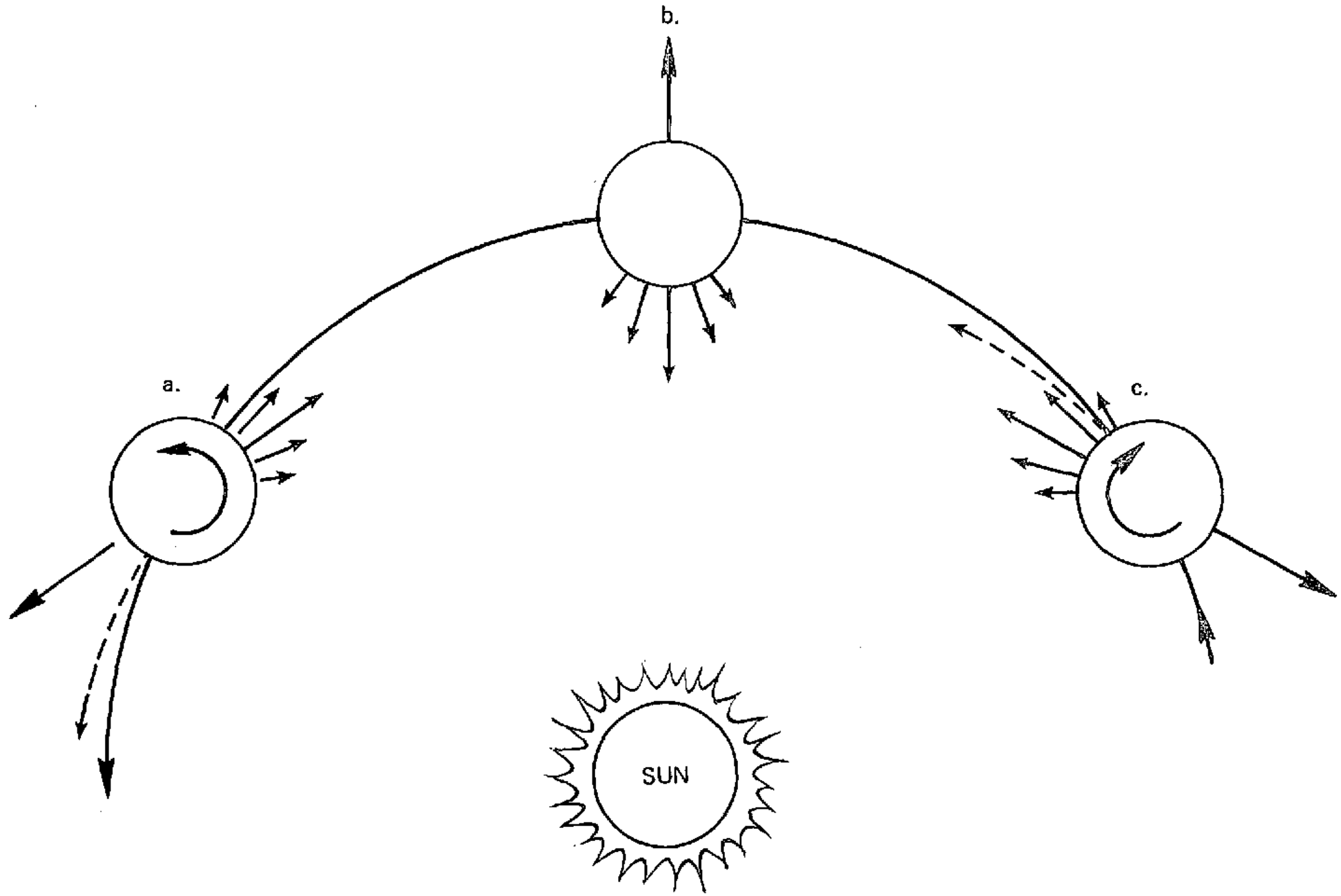
Recently, a great deal of effort has been expended studying the scientific rationale, appropriate instrumentation and optimum mission modes to Comet Encke in 1980. A significant portion of these studies rely upon ephemeris and error analysis data of the comet. A direct comparison of different mission strategies has been difficult because various studies have employed different ephemerides and error estimates of the target comet. It is hoped that the present document will form a consistent basis for future studies of a comet Encke intercept mission in 1980. Although additional future observations of comet Encke will necessitate slight modifications to this data, it is certainly sufficient for preliminary mission planning studies. While an outline of this error analysis has appeared previously (Farquhar et al, 1974), the present document gives a more rigorous treatment of the subject.

II. HISTORICAL EVOLUTION OF IDEAS CONCERNING NONGRAVITATIONAL FORCES AND COMET ENCKE

Comet Encke was discovered as a naked eye object by Méchain during the evening of January 17, 1786. In 1818 Johann Encke demonstrated the orbital similarity of the comets of 1786, 1795, 1805 and 1818. The first precalculated apparition was in 1822 when Dunlop (Australia) recovered the comet on June 2 according to Encke's ephemeris. As early as August 1820, Encke suspected an acceleration in the mean motion of this comet and he later postulated that the comet moved under the influence of a resisting medium, the retarding force being proportional to the square of the comet's velocity and inversely proportional to the square of its heliocentric distance (Encke, 1823). Encke investigated the motion of the comet that bears his name over the interval 1786-1858 and established a secular acceleration of 0.1 day per $(\text{period})^2$. Upon Encke's death in 1865, Asten (Pulkovo) took over the work on comet Encke and his troubles began almost immediately. Post 1868 returns of comet Encke implied that the secular acceleration of this comet was no longer equal to the value during the 1786-1858 interval. Asten made an entirely new study of this comet's motion from 1819 to 1875. His inability to represent the motion of comet Encke after 1868 led him to suggest a near collision with minor planet (78) Diana as a possible cause of this comet's apparently discontinuous behavior. Asten's enormous amount of work on comet Encke for 13 years and his concern over his inability to successfully represent its motion after 1868 led him to an early death at age 36; the same year his research was published (Asten, 1878). Oskar Backlund, also from Pulkovo Observatory, then took over the work and like Asten recomputed the perturbations from 1819. Backlund (1884) concluded that the observations from 1871 to 1881 could be explained in terms of a constant secular acceleration but with a value of 0.05 days per $(\text{period})^2$ instead of the previous 0.1 days per $(\text{period})^2$. Backlund (1910) later indicated that further sudden decreases in the secular acceleration had occurred and concluded that the motion of this comet was affected near perihelion by meteoric collisions of short duration. Makover (1955, 1956) also assumed that impulsive forces acting at perihelion were responsible for the secular acceleration and noted that during the 1937-1954 interval the values had again decreased from what it was in Backlund's time. Marsden (1968, 1969) investigated the motion of comet Encke over the interval 1927-1967 and found a secular acceleration of 0.03-0.05 day per $(\text{period})^2$ and attributed the nongravitational forces to outgassing from the icy-conglomerate model for the cometary nucleus (Whipple, 1950).

Assuming that a cometary nucleus is a collection of volatile ices existing in a coherent structure, the ices will sublimate primarily in a sunward direction. The sunward outgassing would then cause a nongravitational acceleration in the antisolar direction (case b of Figure 1). If the nucleus is rotating (either in a direct or retrograde sense) the time lag between maximum solar flux received and maximum outgassing will produce an in-plane, transverse, nongravitational acceleration component perpendicular to the Sun-comet direction. It is this transverse component that most seriously affects the long term orbital behavior of short period comets. If the cometary nucleus is rotating in a direct sense, the transverse, nongravitational acceleration acts in the direction of the comet's motion, the comet spirals away from the Sun, the orbital period increases and the comet's mean motion is said to be decelerating (case a of Figure 1). If the nucleus is rotating in a retrograde sense, the transverse, nongravitational acceleration acts contrary to the comet's motion, the comet spirals in toward the Sun, the orbital period decreases and the comet's mean motion is said to be accelerating (case c of Figure 1). This last case applies to the observed behavior of comet Encke, and it demonstrates why Johann Encke attributed this comet's behavior to an interplanetary resisting medium; a resisting medium would also cause an acceleration in comet Encke's mean motion. However, an interplanetary resisting medium would not explain the deceleration in mean motion observed for some short period comets.

Using an empirical relationship, Marsden (1969) successfully modeled the nongravitational accelerations acting on several short period comets. Later this empirical relationship was replaced by a representation of a theoretical plot of water snow vaporization flux versus heliocentric distance (Marsden, Sekanina and Yeomans, 1973). While the former empirical relationship was



Depending upon the direction of nuclear rotation, the outgassing cometary volatiles introduce a secular deceleration (case a) or a secular acceleration (case c) in the comet's mean motion. If the cometary nucleus is not rotating (case b), only a radial nongravitational acceleration is introduced.

Figure 1. Origin of Cometary Nongravitational Accelerations

as successful as the latter mathematical model, the latter enabled a more meaningful comparison of the nongravitational parameters for different comets; the nongravitational parameters represent the relative mass-loss rates for the various short period comets. In the preliminary investigations, the magnitude of the transverse nongravitational acceleration decreased with time for several short period comets. This is what would be expected if the comets were slowly exhausting their volatile ices. However, beginning with comet Giacobini-Zinner (Yeomans, 1971), it was noted that, for some comets, the magnitude of the transverse, nongravitational acceleration increased with time. In order to explain the diverse, secular behavior of the transverse, nongravitational component, Marsden and Sekanina (1971) proposed two types of cometary nuclei, a completely ice model and a solid core-ice mantle model. The solid ice model would display a secular increase in the nongravitational forces as the surface to mass ratio increased. The more fragile solid ice model would also be more easily affected by outside influences (such as asteroidal collisions) and would presumably explain the erratic orbital behavior of some short period comets. The solid core-ice mantle model of a cometary nucleus would display a secular decrease in the nongravitational forces as the volatile ices in the outside mantle were exhausted. Unlike the solid ice model, the solid core would remain in existence (perhaps as an asteroid) even after the volatile nuclear ices were exhausted. While secular variations could be explained in terms of secular changes in nuclear radius, density and albedo, it is extremely difficult to explain the behavior of some comets in terms of intrinsic changes in the icy-conglomerate model of the cometary nucleus. For example, the secular acceleration of comet Pons-Winnecke has evolved into a secular deceleration while for comets Faye and Kopff, the reverse is true (Marsden, 1970; Marsden and Sekanina, 1971; Yeomans, 1974). For the latter case, an interpretation in terms of intrinsic changes in the icy-conglomerate model for the cometary nucleus requires an initial direct rotation of the nucleus with a secular decrease in nuclear outgassing and is followed by a retrograde rotation of the nucleus with a secular increase in nuclear outgassing.

Perhaps a more feasible explanation of the phenomena permits the rotation axis of the cometary nucleus to precess. The rotation axis may have precessed through the orbit plane of the comet; the transverse nongravitational component would decrease toward zero, pass through zero and then increase away from zero. The phenomena is explained without resorting to exotic changes in the intrinsic composition of the comet's nucleus. While some secular changes in the nongravitational forces of short period comets are undoubtedly due to intrinsic changes of the nucleus itself, it may well be that these are long-term variations superimposed on the dominant effects due to the orientation of the nuclear rotation axis.

III MATH MODEL AND COMPUTATIONAL PROCEDURE

Equations of motion similar to those used by Marsden, Sekanina and Yeomans (1973) have been employed in the present undertaking. Two nongravitational acceleration terms have been added to the standard equations of motion and the complete vectorial equation is

$$\frac{d^2\vec{r}}{dt^2} = \frac{-\mu\vec{r}}{r^3} + \frac{\partial R}{\partial \vec{r}} + A_1\, g(r)\, \hat{r} + A_2\, g(r)\, \hat{T}$$

where

$$g(r) = \alpha\left(\frac{r}{r_o}\right)^{-m}\left\{1 + \left(\frac{r}{r_o}\right)^{n}\right\}^{-k}$$

The scale distance r_o (2.808 a.u.) is the distance beyond which the nongravitational acceleration drops very rapidly. The exponents m, n and k equal 2.15, 5.093 and 4.6142 respectively. The normalization constant α (0.111262) is set so that $g(1) = 1$. The acceleration is given in astronomical units per $(10^4$ ephemeris days$)^2$; μ is the product of the gravitational constant and the mass of the Sun, and R is the planetary disturbing function. The unit vector $\hat{r}$ is directed outward along the radius vector while $\hat{T}$ is in the orbit plane and advanced 90^o from the radius vector. An acceleration component normal to the orbit plane has been found to have a negligible effect upon the orbital motion of short-period comets (Marsden 1969; Yeomans 1971). If one assumes that the nongravitational forces perturbing the orbits of some comets are due to the rocket effect of outgassing volatiles from the icy-conglomerate nucleus (Whipple 1950), the form of the nongravitational terms represents an empirical fit to a theoretical plot of water snow vaporization flux versus heliocentric distance. A discussion of the nongravitational terms has been given in some detail in the work of Marsden, Sekanina, and Yeomans (1973).

The numerical integrator is a ninth-order predictor-corrector scheme (summed ordinate form) running at 1/2 day time steps (Henrici, 1962). At each step, attractions of all nine planets are taken into account. Planetary and solar coordinates are read from magnetic tapes and integrated variational orbits were used in the differential correction procedure. The numerical integration, formation of residuals, and differential correction were programmed in double precision (15 significant figures) for the IBM 360 computers at the Goddard Space Flight Center.

The observations at each apparition were chosen to include as large an observational arc as possible with the various observations spread uniformly over that arc. When a large number of observations were available for a particular apparition, preference was given to those from a planned series using larger telescopes.

IV. COMET ENCKE ORBIT DETERMINATION AND EPHEMERIDES

Marsden and Sekanina (1974) have analyzed the orbital motion of comet Encke from its discovery in 1786 until 1971. Differential corrections were generally made over 13 year intervals, an interval long enough that the nongravitational parameters become significant and short enough that they can be regarded as constant. Although the radial nongravitational parameter A_1 was poorly determined, their paper graphically illustrates the secular evolution of the transverse nongravitational parameter (Figure 2). After reaching a maximum around 1820, the value of A_2 has decreased toward zero. Marsden and Sekanina note that while A_2 appears to be approaching zero, the value of A_2 may pass through zero around the year 2020 and attain a maximum positive value of about +0.001 by the year 2075.

As a check upon his own work, the present author has repeated a portion of the analysis by Marsden and Sekanina (1974). The observations of comet Encke from 1937-1973 have been utilized for five separate differential corrections. The values of the nongravitational parameters A_1 and A_2 are presented in Table 1. Within the given mean errors, the orbits labeled 1, 2 and 4 agree with similar orbits determined by Marsden and Sekanina (1974). The entries in Tables 2 and 3 represent an attempt to compare observed and predicted times of perihelion passage (Table 2) and perihelion distances (Table 3). In each table, the first column represents the observed time interval over which a particular differential correction was made. The second and third columns give the number of observations employed in each differential correction and the mean of the absolute values of the observational residuals (in the sense observed minus computed). Columns 4-12 give the times of perihelion passage (Table 2) and perihelion distances (Table 3) for each particular interval. For example, in Table 2, line 1, columns 4-8 give the observed times of perihelion passage for 1947, 1951, 1954, 1957 and 1961 while the remaining times of perihelion passage (columns 9-11) are predicted (extrapolated) outside the

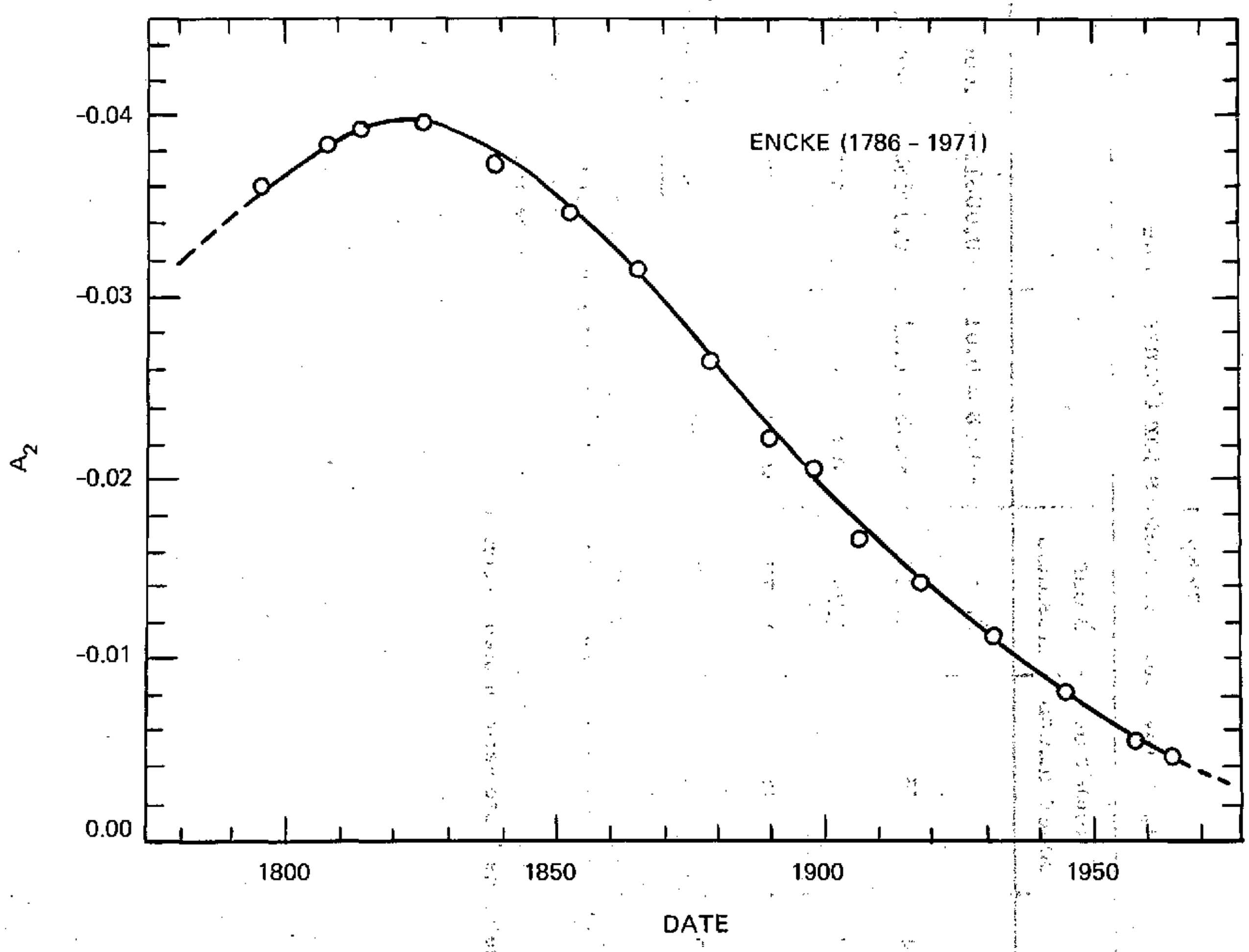


Figure 2. Plot of the transverse nongravitational parameter A_2 versus the time, 1786-1971. Figure taken from Marsden and Sekanina (1974).

Table 1
Nongravitational Parameters for Comet Encke*

Observation Interval	Number of observations	Mean Residual	A_1	A_2
1937-1951	49	2.03"	-0.03 ± 0.01	-0.00811 ± 0.00006
1951-1964	75	1.33"	+0.03 ± 0.01	-0.00582 ± 0.00005
1954-1967	68	1.28"	+0.02 ± 0.01	-0.00527 ± 0.00005
1957-1970	81	1.77"	+0.02 ± 0.01	-0.00475 ± 0.00002
1961-1973	65	1.57"	0.00 ± 0.01	-0.00430 ± 0.00005

*Each orbit (1-5) represents a differential correction employing the given number of observations spread over the given observational interval. As a result of the differential correction, the radial and transverse nongravitational parameters (A_1, A_2) and their mean errors are determined and the final corrected orbit fits the observations to an accuracy given by the mean of the absolute value of the "observed-computed" residuals.

Table 2
Comet Encke
Observed and Predicted Times of Perihelion Passage

Observed Interval	No. of obs.	Mean resid.	1947 Nov.	1951 March	1954 July	1957 Oct.	1961 Feb.	1964 June	1967 Sept.	1971 Jan.	1974 Apr.	1977 Aug.	1980 Dec.	1984 Mar.
1947-1961	76	1.63"	26.32771	16.20639	2.51788	19.84902	5.59452	3.48639	22.04696	9.95477				
1951-1964	75	1.33		16.20842	2.51807	19.84869	5.59494	3.48951	22.05469	9.96845	28.97037			
1954-1967	68	1.28			2.51998	19.84886	5.59500	3.49099	22.05903	9.97727	28.98501	16.97977		
1957-1971	81	1.77				19.84937	5.59419	3.49046	22.06044	9.98221	28.99491	16.99603	6.55148	
1961-1974	65	1.57					5.59477	3.48950	22.05935	9.98232	28.99754	17.00248	6.56310	27.65721

Table 3
Comet Encke
Observed and Predicted Perihelion Distances (in A.U.)

Observed Interval	No. of obs.	Mean resid.	1947 Nov.	1951 March	1954 July	1957 Oct.	1961 Feb.	1964 June	1967 Sept.	1971 Jan.	1974 Apr.	1977 Aug.	1980 Dec.	1984 March
1947-1961	76	1.63"	0.3410319	0.3380089	0.3384086	0.3381187	0.3390047	0.3392511	0.3381997	0.3388910				
1951-1964	75	1.33		0.3380127	0.3384123	0.3381221	0.3390085	0.3392561	0.3382050	0.3388965	0.3381216			
1954-1967	68	1.28			0.3384116	0.3381211	0.3390075	0.3392548	0.3382038	0.3388953	0.3381204	0.3406577		
1957-1971	81	1.77				0.3381260	0.3390125	0.3392600	0.3382089	0.3389005	0.3381256	0.3406628	0.3399416	
1961-1974	65	1.57					0.3390115	0.3392593	0.3382082	0.3388998	0.3381250	0.3406622	0.3399411	0.3410024

observational range (1947-1961). Carrying this example further, the first predicted time of perihelion passage (1964 June 3.48639) is compared with the entry directly below it (1964 June 3.48951) which is the observed or actual time of perihelion passage in 1964. Strictly speaking, any of the 4 times listed below the 1964 June 3.48639 date is an observed time of perihelion passage in 1964; they all are within their respective observational intervals. By comparing each predicted time of perihelion passage with the observed times of perihelion passage, a systematic correction is noted whereby the predicted and observed times of perihelion passage can be brought into agreement. This empirical correction and its standard deviation is

$$\Delta T = +0.00423 \pm 0.00094 \text{ days}$$

This empirical correction (ΔT) is required to allow for the secular decrease in A_2. In other words, by not mathematically modeling this secular decrease in A_2, each predicted time of perihelion passage is underestimated by +0.004 day. In a similar fashion, the empirical corrections to the time of perihelion passage required for predicting 2 and 3 apparitions ahead are +0.013 and +0.03 day respectively. These empirical corrections for predicting 1, 2 and 3 apparitions ahead (+0.004, +0.013, +0.03 day) are similar to the values (+0.005, +0.015, +0.03 day) obtained by Marsden and Sekanina (1974). The differences between the predicted and observed values of the perihelion distance do not exhibit any systematic effects so that no single empirical correction is suitable for this parameter. The range of these Δq corrections is $(0.6 - 8.9) \times 10^{-6}$ a.u. or 90-1335 km. This result will be used as a check on a priori errors in the next section.

Tables 4, 5, 6 give ephemeris information for comet Encke in 1977, 1980 and 1984. In each case, orbit number 5 in Table 1 was used; the appropriate, empirical ΔT correction has been added to the time of perihelion passage.

Comet Encke Ephemerides 1976 - 1984

Tables 4, 5, 6

Explanation of tabular entries

1. Ephemeris table

J. D.	Julian date
R. A. 1950 Dec.	Right ascension and declination referred to mean equator and equinox of 1950.0
R. A. Date Dec.	Right ascension and declination referred to mean equator and equinox of date
DELTA	Geocentric distance of comet in A. U.
R	Heliocentric distance of comet in A. U.
TMAG	Total magnitude = $11.5 + 5 \log \Delta + 10 \log r$ Due to an apparent decrease in intrinsic luminosity, the post perihelion values for TMAG may be optimistic
NMAG	Nuclear magnitude = $16.5 + 5 \log \Delta + 5 \log r + 0.03$ BETA
THETA	Sun-Earth-comet angle in degrees
BETA	Sun-comet-Earth angle in degrees
LAT and LONG	Heliocentric, ecliptic latitude and longitude in degrees, referred to 1950.0.

2. Orbital elements

The perihelion passage time is given as a calendar date and as a Julian day number.

Q	Perihelion distance in A. U.
E	Eccentricity

SOMEGA	Argument of perihelion
LOMEGA	Longitude of ascending node
I	Inclination

Angular elements (SOMEGA, LOMEGA, I) are given in degrees, and are referred to the mean ecliptic and equinox of 1950.0.

Table 4
Ephemeris for Comet Encke (1976-1977)

YR	MN	DY	HR	J.D.	R.A. 1950.0	DEC.	R.A. DATE	DEC.	DELTA	R	TMAG	NMAG	THETA	BETA	LAT	LONG
1976	8	30	0.0	2443020.5	23 46.751	4 11.97	23 48.114	4 20.86	2.6549	3.6068	19.19	21.59	157.18	6.23	3.8	352.5
1976	9	4	0.0	2443025.5	23 41.685	3 48.30	23 43.048	3 57.19	2.6096	3.5863	19.13	21.50	163.07	4.70	3.9	352.8
1976	9	9	0.0	2443030.5	23 36.325	3 21.95	23 37.689	3 30.82	2.5721	3.5654	19.07	21.41	168.77	3.15	3.9	353.1
1976	9	14	0.0	2443035.5	23 30.753	2 53.31	23 32.117	3 2.16	2.5428	3.5439	19.02	21.33	173.44	1.86	4.0	353.4
1976	9	19	0.0	2443040.5	23 25.061	2 22.89	23 26.425	2 31.71	2.5219	3.5220	18.98	21.30	173.66	1.81	4.0	353.7
1976	9	24	0.0	2443045.5	23 19.350	1 51.26	23 20.715	2 0.05	2.5095	3.4996	18.94	21.31	169.08	3.11	4.1	354.1
1976	9	29	0.0	2443050.5	23 13.729	1 19.10	23 15.096	1 27.85	2.5054	3.4766	18.91	21.34	163.27	4.76	4.2	354.4
1976	10	4	0.0	2443055.5	23 8.303	0 47.07	23 9.671	0 55.79	2.5095	3.4532	18.88	21.38	157.18	6.45	4.2	354.7
1976	10	9	0.0	2443060.5	23 3.165	0 15.82	23 4.535	0 24.49	2.5213	3.4293	18.86	21.43	151.03	8.11	4.3	355.0
1976	10	14	0.0	2443065.5	22 58.396	- 0 14.07	22 59.769	- 0 5.44	2.5403	3.4049	18.85	21.48	144.90	9.70	4.4	355.3
1976	10	19	0.0	2443070.5	22 54.069	- 0 42.07	22 55.443	- 0 33.48	2.5659	3.3799	18.84	21.53	138.84	11.18	4.4	355.7
1976	10	24	0.0	2443075.5	22 50.241	- 1 7.72	22 51.617	- 0 59.17	2.5975	3.3544	18.83	21.58	132.88	12.55	4.5	356.0
1976	10	29	0.0	2443080.5	22 46.958	- 1 30.64	22 48.337	- 1 22.12	2.6344	3.3284	18.83	21.63	127.03	13.78	4.6	356.4
1976	11	3	0.0	2443085.5	22 44.247	- 1 50.55	22 45.629	- 1 42.07	2.6756	3.3018	18.82	21.68	121.32	14.87	4.6	356.7
1976	11	8	0.0	2443090.5	22 42.120	- 2 7.29	22 43.502	- 1 58.83	2.7205	3.2747	18.82	21.72	115.75	15.81	4.7	357.1
1976	11	13	0.0	2443095.5	22 40.575	- 2 20.76	22 41.960	- 2 12.31	2.7681	3.2470	18.83	21.77	110.31	16.61	4.8	357.4
1976	11	18	0.0	2443100.5	22 39.609	- 2 30.89	22 40.994	- 2 22.44	2.8179	3.2188	18.83	21.81	105.01	17.25	4.8	357.8
1976	11	23	0.0	2443105.5	22 39.208	- 2 37.67	22 40.595	- 2 29.23	2.8690	3.1900	18.83	21.84	99.85	17.76	4.9	358.2
1976	11	28	0.0	2443110.5	22 39.356	- 2 41.13	22 40.744	- 2 32.68	2.9208	3.1606	18.83	21.87	94.83	18.12	5.0	358.6
1976	12	3	0.0	2443115.5	22 40.027	- 2 41.34	22 41.415	- 2 32.88	2.9724	3.1306	18.82	21.89	89.94	18.35	5.1	358.9
1976	12	8	0.0	2443120.5	22 41.191	- 2 38.40	22 42.580	- 2 29.92	3.0234	3.1000	18.82	21.91	85.18	18.46	5.1	359.3
1976	12	13	0.0	2443125.5	22 42.821	- 2 32.42	22 44.210	- 2 23.91	3.0731	3.0688	18.81	21.93	80.53	18.45	5.2	359.8
1976	12	18	0.0	2443130.5	22 44.892	- 2 23.48	22 46.281	- 2 14.94	3.1211	3.0370	18.80	21.93	76.00	18.32	5.3	0.2
1976	12	23	0.0	2443135.5	22 47.379	- 2 11.68	22 48.763	- 2 3.10	3.1668	3.0045	18.78	21.93	71.58	18.10	5.4	0.6
1976	12	28	0.0	2443140.5	22 50.255	- 1 57.12	22 51.643	- 1 48.52	3.2098	2.9714	18.76	21.93	67.26	17.77	5.4	1.0
1977	1	2	0.0	2443145.5	22 53.492	- 1 39.95	22 54.880	- 1 31.29	3.2497	2.9377	18.74	21.92	63.04	17.36	5.5	1.5
1977	1	7	0.0	2443150.5	22 57.066	- 1 20.25	22 58.453	- 1 11.55	3.2860	2.9032	18.71	21.90	58.92	16.86	5.6	1.9
1977	1	12	0.0	2443155.5	23 0.955	- 0 58.13	23 2.342	- 0 49.39	3.3186	2.8681	18.68	21.88	54.89	16.29	5.7	2.4
1977	1	17	0.0	2443160.5	23 5.141	- 0 33.67	23 6.528	- 0 24.89	3.3472	2.8322	18.64	21.85	50.94	15.65	5.8	2.9
1977	1	22	0.0	2443165.5	23 9.609	- 0 6.96	23 10.995	0 1.86	3.3714	2.7957	18.60	21.82	47.08	14.94	5.9	3.3
1977	1	27	0.0	2443170.5	23 14.341	0 21.91	23 15.725	0 30.78	3.3911	2.7584	18.56	21.78	43.30	14.17	6.0	3.8
1977	2	1	0.0	2443175.5	23 19.319	0 52.85	23 20.705	1 1.76	3.4060	2.7204	18.51	21.73	39.61	13.35	6.1	4.4
1977	2	6	0.0	2443180.5	23 24.531	1 25.79	23 25.917	1 34.74	3.4161	2.6815	18.45	21.68	35.99	12.48	6.2	4.9
1977	2	11	0.0	2443185.5	23 29.969	2 0.66	23 31.355	2 9.64	3.4212	2.6420	18.39	21.63	32.45	11.56	6.3	5.4
1977	2	16	0.0	2443190.5	23 35.627	2 37.40	23 37.014	2 46.42	3.4213	2.6016	18.32	21.57	28.99	10.61	6.4	6.0
1977	2	21	0.0	2443195.5	23 41.499	3 15.98	23 42.885	3 25.01	3.4162	2.5603	18.25	21.50	25.61	9.61	6.5	6.6
1977	2	26	0.0	2443200.5	23 47.577	3 56.31	23 48.965	4 5.37	3.4060	2.5182	18.17	21.42	22.32	8.59	6.6	7.2
1977	3	3	0.0	2443205.5	23 53.858	4 38.34	23 55.243	4 47.42	3.3905	2.4753	18.09	21.35	19.13	7.54	6.7	7.8
1977	3	8	0.0	2443210.5	0 0.342	5 22.04	0 1.735	5 31.12	3.3699	2.4314	18.00	21.26	16.04	6.48	6.8	8.4
1977	3	13	0.0	2443215.5	0 7.034	6 7.38	0 8.423	6 16.46	3.3442	2.3866	17.90	21.17	13.08	5.41	6.9	9.1
1977	3	18	0.0	2443220.5	0 13.938	6 54.34	0 15.337	7 3.41	3.3135	2.3409	17.80	21.08	10.30	4.36	7.0	9.8
1977	3	23	0.0	2443225.5	0 21.062	7 42.89	0 22.464	7 51.94	3.2777	2.2942	17.68	20.98	7.82	3.39	7.1	10.5
1977	3	28	0.0	2443230.5	0 28.412	8 33.00	0 29.819	8 42.03	3.2370	2.2464	17.57	20.89	5.90	2.62	7.3	11.3
1977	4	2	0.0	2443235.5	0 35.998	9 24.65	0 37.411	9 33.64	3.1915	2.1976	17.44	20.80	5.09	2.31	7.4	12.1
1977	4	7	0.0	2443240.5	0 43.839	10 17.84	0 45.257	10 26.78	3.1414	2.1477	17.31	20.73	5.75	2.68	7.5	12.9
1977	4	12	0.0	2443245.5	0 51.956	11 12.57	0 53.381	11 21.44	3.0868	2.0967	17.16	20.66	7.41	3.54	7.7	13.8
1977	4	17	0.0	2443250.5	1 0.372	12 8.85	1 1.805	12 17.64	3.0279	2.0445	17.01	20.60	9.49	4.65	7.8	14.7

Table 4 (continued)
Ephemeris for Comet Encke (1976-1977)

1977	4	22	0.0	2443255.5	1	9.116	13	6.66	1	10.557	13	15.36	2.9649	1.3910	16.85	20.53	11.72	5.88	8.0	15.6
1977	4	27	0.0	2443260.5	1	18.217	14	6.01	1	19.668	14	14.60	2.8979	1.9363	16.68	20.46	13.96	7.20	8.1	16.6
1977	5	2	0.0	2443265.5	1	27.716	15	6.87	1	29.178	15	15.32	2.8273	1.8803	16.50	20.39	16.16	8.58	8.3	17.7
1977	5	7	0.0	2443270.5	1	37.663	16	9.23	1	39.137	16	17.54	2.7532	1.8228	16.31	20.30	18.28	10.00	8.5	18.8
1977	5	12	0.0	2443275.5	1	48.118	17	13.09	1	49.505	17	21.22	2.6761	1.7639	16.10	20.21	20.32	11.47	8.6	20.1
1977	5	17	0.0	2443280.5	1	59.150	18	18.37	2	0.653	18	26.29	2.5961	1.7035	15.89	20.12	22.23	12.98	8.8	21.4
1977	5	22	0.0	2443285.5	2	10.837	19	24.98	2	12.357	19	32.66	2.5136	1.6415	15.65	20.01	24.02	14.54	9.0	22.8
1977	5	27	0.0	2443290.5	2	23.274	20	32.72	2	24.813	20	40.13	2.4290	1.5777	15.41	19.90	25.64	16.14	9.2	24.3
1977	6	1	0.0	2443295.5	2	36.577	21	41.34	2	38.136	21	48.42	2.3427	1.5122	15.14	19.78	27.09	17.78	9.4	25.9
1977	6	6	0.0	2443300.5	2	50.887	22	50.43	2	52.467	22	57.14	2.2552	1.4448	14.86	19.65	28.34	19.48	9.6	27.7
1977	6	11	0.0	2443305.5	3	6.369	23	59.39	3	7.974	24	5.67	2.1670	1.3754	14.56	19.51	29.36	21.22	9.9	29.7
1977	6	16	0.0	2443310.5	3	23.216	25	7.33	3	24.845	25	13.10	2.0788	1.3039	14.24	19.36	30.12	23.02	10.1	31.9
1977	6	21	0.0	2443315.5	3	41.646	26	12.92	3	43.302	26	18.10	1.9911	1.2301	13.89	19.19	30.58	24.85	10.4	34.4
1977	6	26	0.0	2443320.5	4	1.911	27	14.24	4	3.594	27	18.74	1.9049	1.1539	13.52	19.01	30.68	26.71	10.7	37.2
1977	7	1	0.0	2443325.5	4	24.292	28	8.62	4	26.001	28	12.31	1.8212	1.0752	13.12	18.82	30.39	28.58	10.9	40.3
1977	7	6	0.0	2443330.5	4	49.083	28	52.31	4	50.814	28	55.08	1.7410	0.9938	12.68	18.60	29.63	30.39	11.2	44.1
1977	7	11	0.0	2443335.5	5	16.656	29	20.31	5	18.405	29	22.01	1.6656	0.9097	12.20	18.36	28.36	32.06	11.5	48.5
1977	7	16	0.0	2443340.5	5	46.918	29	26.07	5	48.674	29	26.56	1.5966	0.8229	11.67	18.10	26.48	33.42	11.7	53.8
1977	7	21	0.0	2443345.5	6	20.246	29	1.53	6	21.997	29	0.68	1.5353	0.7335	11.09	17.78	23.94	34.20	11.9	60.4
1977	7	26	0.0	2443350.5	6	56.442	27	57.38	6	58.169	27	55.11	1.4834	0.6422	10.43	17.41	20.65	33.90	11.9	68.9
1977	7	31	0.0	2443355.5	7	35.212	26	3.83	7	36.899	26	0.08	1.4418	0.5508	9.70	16.95	16.55	31.66	11.5	80.1
1977	8	5	0.0	2443360.5	8	16.123	23	11.63	8	17.754	23	6.45	1.4101	0.4532	8.90	16.36	11.55	26.01	10.2	95.7
1977	8	10	0.0	2443365.5	8	58.639	19	14.17	9	0.204	19	7.66	1.3846	0.3888	8.10	15.60	5.63	14.83	7.2	117.7
1977	8	15	0.0	2443370.5	9	41.925	14	13.16	9	43.427	14	5.54	1.3566	0.3450	7.54	14.97	1.39	4.08	1.5	146.9
1977	8	20	0.0	2443375.5	10	24.456	8	29.42	10	25.903	8	20.97	1.3185	0.3501	7.54	15.57	8.39	24.95	-5.2	179.5
1977	8	25	0.0	2443380.5	11	4.867	2	37.31	11	6.293	2	28.34	1.2756	0.4017	8.07	16.29	15.29	41.56	-9.6	207.6
1977	8	30	0.0	2443385.5	11	43.200	- 2	59.78	11	44.614	- 3	8.99	1.2411	0.4799	8.78	16.90	21.64	50.89	-11.5	228.3
1977	9	4	0.0	2443390.5	12	20.107	- 8	11.24	12	21.533	- 8	20.45	1.2236	0.5587	9.49	17.35	27.42	54.73	-11.9	242.9
1977	9	9	0.0	2443395.5	12	55.962	-12	50.30	12	57.415	-12	59.27	1.2254	0.6604	10.14	17.70	32.58	55.22	-11.8	253.6
1977	9	14	0.0	2443400.5	13	30.755	-16	51.80	13	32.247	-17	0.32	1.2460	0.7513	10.74	17.97	37.08	53.82	-11.4	261.6
1977	9	19	0.0	2443405.5	14	4.245	-20	13.13	14	5.783	-20	21.05	1.2836	0.8402	11.29	18.21	40.85	51.44	-11.0	267.9
1977	9	24	0.0	2443410.5	14	36.129	-22	54.84	14	37.715	-23	2.01	1.3357	0.9266	11.80	18.42	43.87	48.62	-10.5	273.0
1977	9	29	0.0	2443415.5	15	6.159	-25	0.06	15	7.791	-25	6.41	1.3998	1.0101	12.27	18.62	46.16	45.66	-10.1	277.2
1977	10	4	0.0	2443420.5	15	34.194	-26	33.53	15	35.865	-26	39.01	1.4737	1.0909	12.72	18.81	47.75	42.74	-9.6	280.8
1977	10	9	0.0	2443425.5	16	0.205	-27	40.46	16	1.913	-27	45.06	1.5553	1.1691	13.14	19.00	48.72	39.95	-9.2	283.9
1977	10	14	0.0	2443430.5	16	24.255	-28	25.88	16	25.985	-28	29.61	1.6428	1.2448	13.53	19.17	49.14	37.30	-8.9	286.5
1977	10	19	0.0	2443435.5	16	46.463	-28	54.16	16	48.212	-28	57.06	1.7347	1.3181	13.90	19.34	49.07	34.81	-8.5	288.9
1977	10	24	0.0	2443440.5	17	6.979	-29	8.93	17	8.741	-29	11.03	1.8298	1.3893	14.24	19.50	48.59	32.48	-8.2	291.1
1977	10	29	0.0	2443445.5	17	25.971	-29	13.12	17	27.739	-29	14.45	1.9271	1.4583	14.56	19.65	47.76	30.28	-7.9	293.0
1977	11	3	0.0	2443450.5	17	43.607	-29	8.99	17	45.378	-29	9.62	2.0257	1.5253	14.87	19.80	46.61	28.20	-7.7	294.7
1977	11	8	0.0	2443455.5	18	0.048	-28	58.35	18	1.818	-28	58.31	2.1249	1.5904	15.15	19.93	45.19	26.23	-7.4	296.3
1977	11	13	0.0	2443460.5	18	15.435	-28	42.56	18	17.202	-28	41.89	2.2241	1.6538	15.42	20.06	43.55	24.35	-7.1	297.8
1977	11	18	0.0	2443465.5	18	29.892	-28	22.68	18	31.652	-28	21.43	2.3225	1.7156	15.67	20.18	41.70	22.54	-6.9	299.2
1977	11	23	0.0	2443470.5	18	43.522	-27	59.53	18	45.274	-27	57.73	2.4198	1.7757	15.91	20.29	39.69	20.80	-6.7	300.5
1977	11	28	0.0	2443475.5	18	56.419	-27	33.73	18	58.163	-27	31.42	2.5155	1.8343	16.14	20.39	37.52	19.12	-6.5	301.7
1977	12	3	0.0	2443480.5	19	8.667	-27	5.76	19	10.400	-27	2.98	2.6093	1.8914	16.35	20.49	35.22	17.49	-6.3	302.8
1977	12	8	0.0	2443485.5	19	20.337	-26	36.02	19	22.060	-26	33.79	2.7006	1.9472	16.55	20.58	32.80	15.91	-6.1	303.8
1977	12	13	0.0	2443490.5	19	31.489	-26	4.82	19	33.201	-26	1.16	2.7893	2.0017	16.74	20.67	30.28	14.36	-5.9	304.8

Table 4 (continued)
Ephemeris for Comet Encke (1976-1977)

1977	12	18	0.0	2443495.5	19 42.171	-25 32.42	19 43.871	-25 28.36	2.8748	2.0549	16.92	20.74	27.67	12.85	-5.8 305.7
1977	12	23	0.0	2443500.5	19 52.421	-24 59.03	19 54.109	-24 54.60	2.9570	2.1068	17.09	20.81	24.98	11.37	-5.6 306.6

THE ABOVE EPHEMERIS IS BASED ON THE FOLLOWING ECLIPTIC (1950.0) ORBITAL ELEMENTS.

YR	MN	DY	HR	J.D.	Q	E	SOMEGA	LOMEGA	I
1977	8	17	0.2	2443372.50648	0.3406622	0.8464721	185.95340	334.20941	11.93883

Table 5
Ephemeris for Comet Encke (1980-1981)

YR	MN	DY	HR	J.D.	R.A. 1950.0	DEC.	R.A. DATE	DEC.	DELTA	R	TMAG	NMAG	THETA	BETA	LAT	LONG
1980	6	1	0.0	2444391.5	1 13.152	13 17.87	1 14.761	13 27.50	3.2155	2.6549	18.28	21.66	48.53	16.63	6.2	5.2
1980	6	3	0.0	2444393.5	1 15.570	13 36.34	1 17.182	13 45.94	3.1779	2.6390	18.23	21.63	49.77	17.07	6.3	5.5
1980	6	5	0.0	2444395.5	1 17.994	13 54.90	1 19.610	14 4.47	3.1398	2.6229	18.17	21.60	51.02	17.50	6.3	5.7
1980	6	7	0.0	2444397.5	1 20.424	14 13.54	1 22.043	14 23.07	3.1012	2.6067	18.12	21.58	52.26	17.93	6.3	5.9
1980	6	9	0.0	2444399.5	1 22.859	14 32.26	1 24.482	14 41.76	3.0622	2.5903	18.06	21.55	53.51	18.37	6.4	6.1
1980	6	11	0.0	2444401.5	1 25.300	14 51.08	1 26.926	15 0.54	3.0227	2.5738	18.01	21.52	54.75	18.80	6.4	6.4
1980	6	13	0.0	2444403.5	1 27.747	15 9.98	1 29.375	15 19.40	2.9828	2.5572	17.95	21.49	55.99	19.22	6.5	6.6
1980	6	15	0.0	2444405.5	1 30.198	15 28.98	1 31.831	15 38.36	2.9425	2.5405	17.89	21.46	57.23	19.65	6.5	6.8
1980	6	17	0.0	2444407.5	1 32.655	15 48.07	1 34.292	15 57.41	2.9018	2.5236	17.83	21.43	58.46	20.07	6.6	7.1
1980	6	19	0.0	2444409.5	1 35.117	16 7.25	1 36.758	16 16.55	2.8607	2.5065	17.77	21.39	59.70	20.49	6.6	7.3
1980	6	21	0.0	2444411.5	1 37.585	16 26.54	1 39.230	16 35.80	2.8193	2.4893	17.71	21.36	60.93	20.91	6.6	7.6
1980	6	23	0.0	2444413.5	1 40.058	16 45.94	1 41.707	16 55.15	2.7775	2.4720	17.65	21.32	62.16	21.32	6.7	7.8
1980	6	25	0.0	2444415.5	1 42.538	17 5.45	1 44.191	17 14.61	2.7354	2.4546	17.58	21.29	63.39	21.73	6.7	8.1
1980	6	27	0.0	2444417.5	1 45.024	17 25.07	1 46.681	17 34.19	2.6930	2.4370	17.52	21.25	64.62	22.14	6.8	8.3
1980	6	29	0.0	2444419.5	1 47.516	17 44.83	1 49.177	17 53.89	2.6503	2.4192	17.45	21.21	65.84	22.55	6.8	8.6
1980	7	1	0.0	2444421.5	1 50.015	18 4.71	1 51.681	18 13.73	2.6074	2.4013	17.39	21.17	67.07	22.95	6.9	8.9
1980	7	3	0.0	2444423.5	1 52.522	18 24.75	1 54.192	18 33.71	2.5641	2.3832	17.32	21.13	68.29	23.35	6.9	9.1
1980	7	5	0.0	2444425.5	1 55.036	18 44.93	1 56.711	18 53.84	2.5206	2.3650	17.25	21.09	69.51	23.75	7.0	9.4
1980	7	7	0.0	2444427.5	1 57.557	19 5.27	1 59.237	19 14.13	2.4769	2.3466	17.17	21.05	70.73	24.14	7.0	9.7
1980	7	9	0.0	2444429.5	2 0.085	19 25.78	2 1.770	19 34.59	2.4329	2.3281	17.10	21.00	71.95	24.53	7.1	10.0
1980	7	11	0.0	2444431.5	2 2.621	19 46.47	2 4.311	19 55.22	2.3888	2.3094	17.03	20.96	73.17	24.92	7.1	10.3
1980	7	13	0.0	2444433.5	2 5.164	20 7.34	2 6.859	20 16.04	2.3444	2.2906	16.95	20.91	74.39	25.30	7.2	10.6
1980	7	15	0.0	2444435.5	2 7.715	20 28.41	2 9.415	20 37.05	2.2999	2.2716	16.87	20.86	75.60	25.68	7.2	10.9
1980	7	17	0.0	2444437.5	2 10.274	20 49.69	2 11.979	20 58.27	2.2552	2.2524	16.79	20.81	76.81	26.06	7.3	11.2
1980	7	19	0.0	2444439.5	2 12.842	21 11.20	2 14.552	21 19.71	2.2104	2.2331	16.71	20.76	78.03	26.43	7.3	11.5
1980	7	21	0.0	2444441.5	2 15.419	21 32.94	2 17.135	21 41.40	2.1655	2.2135	16.63	20.71	79.24	26.80	7.4	11.8
1980	7	23	0.0	2444443.5	2 18.006	21 54.94	2 19.723	22 3.33	2.1204	2.1938	16.54	20.65	80.44	27.17	7.4	12.1
1980	7	25	0.0	2444445.5	2 20.604	22 17.23	2 22.332	22 25.55	2.0753	2.1740	16.46	20.60	81.65	27.53	7.5	12.4
1980	7	27	0.0	2444447.5	2 23.215	22 39.80	2 24.943	22 48.06	2.0302	2.1539	16.37	20.54	82.85	27.89	7.5	12.8
1980	7	29	0.0	2444449.5	2 25.838	23 2.70	2 27.573	23 10.90	1.9849	2.1337	16.28	20.48	84.05	28.25	7.6	13.1
1980	7	31	0.0	2444451.5	2 28.476	23 25.95	2 30.222	23 34.07	1.9397	2.1133	16.19	20.42	85.24	28.60	7.6	13.4
1980	8	2	0.0	2444453.5	2 31.129	23 49.58	2 32.881	23 57.63	1.8944	2.0927	16.09	20.36	86.44	28.95	7.7	13.8
1980	8	4	0.0	2444455.5	2 33.798	24 13.60	2 35.557	24 21.58	1.8491	2.0719	16.00	20.30	87.63	29.29	7.7	14.2
1980	8	6	0.0	2444457.5	2 36.483	24 38.06	2 38.249	24 45.96	1.8038	2.0510	15.90	20.23	88.81	29.63	7.8	14.5
1980	8	8	0.0	2444459.5	2 39.187	25 2.98	2 40.960	25 10.81	1.7585	2.0298	15.80	20.16	89.99	29.97	7.9	14.9
1980	8	10	0.0	2444461.5	2 41.911	25 28.40	2 43.691	25 36.15	1.7133	2.0084	15.70	20.09	91.17	30.30	7.9	15.3
1980	8	12	0.0	2444463.5	2 44.656	25 54.36	2 46.443	26 2.03	1.6681	1.9869	15.59	20.02	92.34	30.64	8.0	15.7
1980	8	14	0.0	2444465.5	2 47.424	26 20.90	2 49.219	26 28.49	1.6230	1.9651	15.49	19.95	93.51	30.96	8.0	16.1
1980	8	16	0.0	2444467.5	2 50.219	26 48.07	2 52.022	26 55.58	1.5781	1.9431	15.38	19.87	94.67	31.29	8.1	16.5
1980	8	18	0.0	2444469.5	2 53.044	27 15.92	2 54.855	27 23.35	1.5332	1.9209	15.26	19.79	95.82	31.61	8.2	16.9
1980	8	20	0.0	2444471.5	2 55.901	27 44.52	2 57.721	27 51.86	1.4885	1.8985	15.15	19.71	96.96	31.94	8.2	17.3
1980	8	22	0.0	2444473.5	2 58.797	28 13.93	3 0.625	28 21.18	1.4439	1.8759	15.03	19.63	98.09	32.26	8.3	17.8
1980	8	24	0.0	2444475.5	3 1.734	28 44.23	3 3.573	28 51.38	1.3996	1.8530	14.91	19.55	99.21	32.58	8.4	18.2
1980	8	26	0.0	2444477.5	3 4.720	29 15.49	3 6.568	29 22.55	1.3554	1.8299	14.78	19.46	100.32	32.91	8.4	18.7
1980	8	28	0.0	2444479.5	3 7.760	29 47.81	3 9.618	29 54.77	1.3114	1.8066	14.66	19.37	101.41	33.23	8.5	19.1
1980	8	30	0.0	2444481.5	3 10.861	30 21.30	3 12.729	30 28.16	1.2676	1.7831	14.53	19.28	102.49	33.56	8.6	19.6
1980	9	1	0.0	2444483.5	3 14.030	30 56.06	3 15.909	31 2.81	1.2240	1.7593	14.39	19.18	103.54	33.89	8.6	20.1

Table 5 (continued)
Ephemeris for Comet Encke (1980-1981)

1980	9	3	0.0	2444485.5	3	17.277	31	32.21	3	19.163	31	38.86	1.1808	1.7352	14.25	19.08	104.58	34.23	8.7	20.6
1980	9	5	0.0	2444487.5	3	20.612	32	9.91	3	22.515	32	16.44	1.1378	1.7109	14.11	18.98	105.59	34.58	8.8	21.2
1980	9	7	0.0	2444489.5	3	24.047	32	49.29	3	25.963	32	55.70	1.0950	1.6864	13.97	18.88	106.57	34.94	8.9	21.7
1980	9	9	0.0	2444491.5	3	27.599	33	30.53	3	29.529	33	36.82	1.0527	1.6616	13.82	18.77	107.52	35.31	8.9	22.3
1980	9	11	0.0	2444493.5	3	31.284	34	13.83	3	33.229	34	19.99	1.0106	1.6365	13.66	18.66	108.44	35.70	9.0	22.8
1980	9	13	0.0	2444495.5	3	35.127	34	59.42	3	37.088	35	5.44	0.9689	1.6112	13.50	18.55	109.31	36.11	9.1	23.4
1980	9	15	0.0	2444497.5	3	39.154	35	47.53	3	41.132	35	53.41	0.9276	1.5855	13.34	18.43	110.14	36.54	9.2	24.1
1980	9	17	0.0	2444499.5	3	43.399	36	38.47	3	45.395	36	44.19	0.8868	1.5596	13.17	18.31	110.91	37.01	9.3	24.7
1980	9	19	0.0	2444501.5	3	47.901	37	32.56	3	49.917	37	38.11	0.8464	1.5334	12.99	18.19	111.61	37.52	9.4	25.3
1980	9	21	0.0	2444503.5	3	52.712	38	30.16	3	54.750	38	35.54	0.8064	1.5069	12.81	18.07	112.24	38.07	9.4	26.0
1980	9	23	0.0	2444505.5	3	57.893	39	31.71	3	59.955	39	36.88	0.7670	1.4801	12.63	17.94	112.78	38.68	9.5	26.7
1980	9	25	0.0	2444507.5	4	3.523	40	37.66	4	5.512	40	42.61	0.7281	1.4530	12.43	17.80	113.22	39.36	9.6	27.5
1980	9	27	0.0	2444509.5	4	9.699	41	48.54	4	11.819	41	53.26	0.6898	1.4256	12.23	17.67	113.53	40.13	9.7	28.2
1980	9	29	0.0	2444511.5	4	16.550	43	4.94	4	18.703	43	9.37	0.6522	1.3978	12.03	17.53	113.71	41.00	9.8	29.0
1980	10	1	0.0	2444513.5	4	24.237	44	27.44	4	26.428	44	31.57	0.6153	1.3697	11.81	17.39	113.72	42.00	9.9	29.8
1980	10	3	0.0	2444515.5	4	32.977	45	56.67	4	35.212	46	0.43	0.5791	1.3413	11.59	17.25	113.54	43.14	10.0	30.7
1980	10	5	0.0	2444517.5	4	43.061	47	33.16	4	45.345	47	36.50	0.5439	1.3126	11.36	17.10	113.12	44.48	10.1	31.6
1980	10	7	0.0	2444519.5	4	54.883	49	17.30	4	57.225	49	20.13	0.5096	1.2834	11.12	16.96	112.44	46.03	10.2	32.5
1980	10	9	0.0	2444521.5	5	8.980	51	9.04	5	11.387	51	11.26	0.4764	1.2539	10.87	16.82	111.42	47.86	10.3	33.5
1980	10	11	0.0	2444523.5	5	26.095	53	7.53	5	28.576	53	8.99	0.4446	1.2240	10.62	16.68	110.03	50.01	10.4	34.5
1980	10	13	0.0	2444525.5	5	47.240	55	10.38	5	49.801	55	10.89	0.4144	1.1937	10.36	16.55	108.18	52.56	10.5	35.6
1980	10	15	0.0	2444527.5	6	13.744	57	12.40	6	16.383	57	11.72	0.3860	1.1630	10.09	16.43	105.81	55.57	10.6	36.7
1980	10	17	0.0	2444529.5	6	47.181	59	3.77	6	49.875	59	1.60	0.3598	1.1320	9.82	16.32	102.81	59.13	10.7	37.9
1980	10	19	0.0	2444531.5	7	28.928	60	27.79	7	31.622	60	23.84	0.3362	1.1005	9.55	16.24	99.13	63.31	10.9	39.2
1980	10	21	0.0	2444533.5	8	19.030	61	0.19	8	21.519	60	54.27	0.3158	1.0686	9.29	16.19	94.70	68.17	11.0	40.6
1980	10	23	0.0	2444535.5	9	14.686	60	13.70	9	17.049	60	5.93	0.2992	1.0363	9.03	16.17	89.50	73.72	11.1	42.0
1980	10	25	0.0	2444537.5	10	10.261	57	49.96	10	12.336	57	40.80	0.2870	1.0035	8.81	16.19	83.58	79.90	11.2	43.5
1980	10	27	0.0	2444539.5	11	0.150	53	50.59	11	1.967	53	40.63	0.2798	0.9703	8.60	16.27	77.10	86.58	11.3	45.2
1980	10	29	0.0	2444541.5	11	41.604	48	36.55	11	43.243	48	26.28	0.2781	0.9367	8.44	16.38	70.29	93.49	11.4	46.9
1980	10	31	0.0	2444543.5	12	14.707	42	38.06	12	16.244	42	27.78	0.2818	0.9026	8.31	16.54	63.45	100.33	11.5	48.8
1980	11	2	0.0	2444545.5	12	40.851	36	24.59	12	42.340	36	14.46	0.2911	0.8681	8.21	16.72	56.89	106.80	11.6	50.8
1980	11	4	0.0	2444547.5	13	1.618	30	19.05	13	3.091	30	9.13	0.3055	0.8331	8.13	16.91	50.84	112.64	11.7	53.0
1980	11	6	0.0	2444549.5	13	18.346	24	36.02	13	19.823	24	26.33	0.3246	0.7977	8.08	17.10	45.45	117.70	11.8	55.4
1980	11	8	0.0	2444551.5	13	32.060	19	22.66	13	33.545	19	13.19	0.3478	0.7619	8.03	17.27	40.77	121.88	11.9	58.0
1980	11	10	0.0	2444553.5	13	43.522	14	40.79	13	45.025	14	31.53	0.3747	0.7258	7.98	17.43	36.81	125.17	11.9	60.9
1980	11	12	0.0	2444555.5	13	53.299	10	29.00	13	54.820	10	19.94	0.4049	0.6894	7.92	17.56	33.51	127.57	11.9	64.1
1980	11	14	0.0	2444557.5	14	1.819	6	44.27	14	3.357	6	35.40	0.4382	0.6527	7.86	17.65	30.81	129.08	11.9	67.7
1980	11	16	0.0	2444559.5	14	9.418	3	23.02	14	10.979	3	14.33	0.4744	0.6160	7.78	17.72	28.64	129.69	11.8	71.6
1980	11	18	0.0	2444561.5	14	16.372	0	21.66	14	17.952	0	13.13	0.5135	0.5793	7.68	17.75	26.93	129.41	11.7	76.1
1980	11	20	0.0	2444563.5	14	22.917	- 2	23.18	14	24.517	- 2	31.54	0.5555	0.5429	7.57	17.74	25.59	128.17	11.4	81.2
1980	11	22	0.0	2444565.5	14	29.270	- 4	54.45	14	30.889	- 5	2.63	0.6005	0.5071	7.44	17.70	24.57	125.94	11.0	86.9
1980	11	24	0.0	2444567.5	14	35.638	- 7	14.71	14	37.275	- 7	22.72	0.6486	0.4725	7.30	17.61	23.77	122.64	10.4	93.5
1980	11	26	0.0	2444569.5	14	42.232	- 9	26.16	14	43.890	- 9	33.98	0.7000	0.4396	7.16	17.49	23.12	118.17	9.6	101.1
1980	11	28	0.0	2444571.5	14	49.271	-11	30.54	14	50.950	-11	38.15	0.7547	0.4094	7.01	17.32	22.55	112.45	8.4	109.9
1980	11	30	0.0	2444573.5	14	56.976	-13	29.13	14	58.675	-13	36.50	0.8126	0.3829	6.88	17.13	21.98	105.42	6.8	119.8
1980	12	2	0.0	2444575.5	15	5.555	-15	22.60	15	7.277	-15	29.69	0.8735	0.3617	6.79	16.91	21.35	97.11	4.8	131.0
1980	12	4	0.0	2444577.5	15	15.167	-17	10.90	15	16.913	-17	17.68	0.9364	0.3470	6.76	16.69	20.60	87.71	2.3	143.2
1980	12	6	0.0	2444579.5	15	25.875	-18	53.26	15	27.645	-18	59.67	1.0003	0.3403	6.82	16.49	19.72	77.64	-0.4	156.2

Table 5 (continued)
Ephemeris for Comet Encke (1980-1981)

1980	12	8	0.0	2444581.5	15	37.604	-20	28.34	15	39.399	-20	34.32	1.0639	0.3421	6.98	16.33	18.72	67.49	-3.2	169.0
1980	12	10	0.0	2444583.5	15	50.148	-21	54.71	15	51.968	-22	0.22	1.1259	0.3523	7.23	16.23	17.64	57.86	-5.7	182.2
1980	12	12	0.0	2444585.5	16	3.226	-23	11.33	16	5.073	-23	16.34	1.1854	0.3700	7.55	16.19	16.54	49.24	-7.7	194.2
1980	12	14	0.0	2444587.5	16	16.549	-24	17.80	16	18.415	-24	22.27	1.2419	0.3936	7.92	16.20	15.47	41.84	-9.3	204.9
1980	12	16	0.0	2444589.5	16	29.873	-25	14.31	16	31.760	-25	18.23	1.2955	0.4218	8.31	16.26	14.48	35.68	-10.4	214.4
1980	12	18	0.0	2444591.5	16	43.018	-26	1.51	16	44.923	-26	4.88	1.3464	0.4533	8.71	16.35	13.58	30.65	-11.1	222.7
1980	12	20	0.0	2444593.5	16	55.863	-26	40.23	16	57.783	-26	43.04	1.3948	0.4870	9.10	16.46	12.80	26.59	-11.6	229.9
1980	12	22	0.0	2444595.5	17	8.333	-27	11.39	17	10.265	-27	13.66	1.4411	0.5222	9.47	16.58	12.14	23.34	-11.8	236.2
1980	12	24	0.0	2444597.5	17	20.387	-27	35.89	17	22.329	-27	37.62	1.4856	0.5583	9.83	16.72	11.59	20.72	-11.9	241.7
1980	12	26	0.0	2444599.5	17	32.005	-27	54.55	17	33.955	-27	55.76	1.5285	0.5948	10.17	16.85	11.14	18.63	-11.9	246.5
1980	12	28	0.0	2444601.5	17	43.183	-28	8.12	17	45.139	-28	8.83	1.5701	0.6315	10.48	16.99	10.80	16.96	-11.9	250.7
1980	12	30	0.0	2444603.5	17	53.926	-28	17.25	17	55.885	-28	17.48	1.6104	0.6683	10.78	17.13	10.54	15.61	-11.8	254.5
1981	1	1	0.0	2444605.5	18	4.246	-28	22.54	18	6.205	-28	22.31	1.6496	0.7049	11.07	17.26	10.37	14.54	-11.6	257.9
1981	1	3	0.0	2444607.5	18	14.155	-28	24.48	18	16.115	-28	23.80	1.6877	0.7412	11.34	17.40	10.27	13.68	-11.5	260.9
1981	1	5	0.0	2444609.5	18	23.672	-28	23.52	18	25.632	-28	22.41	1.7249	0.7772	11.59	17.53	10.24	13.00	-11.3	263.7
1981	1	7	0.0	2444611.5	18	32.814	-28	20.04	18	34.771	-28	18.52	1.7612	0.8128	11.83	17.65	10.28	12.47	-11.1	266.2
1981	1	9	0.0	2444613.5	18	41.599	-28	14.37	18	43.552	-28	12.46	1.7966	0.8480	12.06	17.78	10.38	12.06	-10.9	268.5
1981	1	11	0.0	2444615.5	18	50.044	-28	6.81	18	51.994	-28	4.52	1.8312	0.8828	12.27	17.90	10.53	11.75	-10.7	270.6
1981	1	13	0.0	2444617.5	18	58.169	-27	57.60	19	0.113	-27	54.96	1.8649	0.9171	12.48	18.01	10.74	11.53	-10.5	272.6
1981	1	15	0.0	2444619.5	19	5.988	-27	46.97	19	7.927	-27	43.99	1.8979	0.9510	12.67	18.12	11.00	11.38	-10.4	274.4
1981	1	17	0.0	2444621.5	19	13.520	-27	35.11	19	15.453	-27	31.80	1.9300	0.9845	12.86	18.23	11.31	11.30	-10.2	276.1
1981	1	19	0.0	2444623.5	19	20.781	-27	22.19	19	22.706	-27	18.57	1.9614	1.0175	13.04	18.34	11.67	11.28	-10.0	277.6
1981	1	21	0.0	2444625.5	19	27.784	-27	8.35	19	29.703	-27	4.43	1.9919	1.0500	13.21	18.44	12.08	11.31	-9.8	279.1
1981	1	23	0.0	2444627.5	19	34.545	-26	53.73	19	36.457	-26	49.53	2.0217	1.0822	13.37	18.54	12.53	11.38	-9.7	280.5
1981	1	25	0.0	2444629.5	19	41.077	-26	38.43	19	42.981	-26	33.96	2.0507	1.1139	13.53	18.64	13.03	11.49	-9.5	281.8
1981	1	27	0.0	2444631.5	19	47.393	-26	22.57	19	49.289	-26	17.84	2.0789	1.1452	13.68	18.73	13.56	11.64	-9.4	283.0
1981	1	29	0.0	2444633.5	19	53.503	-26	6.22	19	55.392	-26	1.25	2.1063	1.1761	13.82	18.82	14.14	11.81	-9.2	284.2
1981	1	31	0.0	2444635.5	19	59.418	-25	49.46	20	1.300	-25	44.26	2.1329	1.2066	13.96	18.91	14.76	12.01	-9.1	285.3
1981	2	2	0.0	2444637.5	20	5.149	-25	32.37	20	7.023	-25	26.94	2.1587	1.2367	14.09	19.00	15.42	12.23	-8.9	286.4
1981	2	4	0.0	2444639.5	20	10.704	-25	15.01	20	12.571	-25	9.36	2.1837	1.2664	14.22	19.08	16.11	12.47	-8.8	287.4
1981	2	6	0.0	2444641.5	20	16.092	-24	57.42	20	17.951	-24	51.57	2.2078	1.2958	14.35	19.16	16.83	12.73	-8.6	288.3
1981	2	8	0.0	2444643.5	20	21.321	-24	39.67	20	23.172	-24	33.62	2.2312	1.3248	14.46	19.24	17.59	13.01	-8.5	289.2
1981	2	10	0.0	2444645.5	20	26.397	-24	21.78	20	28.241	-24	15.55	2.2537	1.3534	14.58	19.32	18.38	13.29	-8.4	290.1
1981	2	12	0.0	2444647.5	20	31.328	-24	3.81	20	33.165	-23	57.40	2.2753	1.3817	14.69	19.39	19.20	13.59	-8.3	290.9
1981	2	14	0.0	2444649.5	20	36.120	-23	45.79	20	37.950	-23	39.21	2.2961	1.4096	14.80	19.47	20.04	13.89	-8.1	291.7
1981	2	16	0.0	2444651.5	20	40.780	-23	27.74	20	42.603	-23	20.99	2.3161	1.4372	14.90	19.54	20.92	14.21	-8.0	292.5
1981	2	18	0.0	2444653.5	20	45.313	-23	9.69	20	47.129	-23	2.79	2.3353	1.4645	15.00	19.61	21.82	14.53	-7.9	293.2
1981	2	20	0.0	2444655.5	20	49.724	-22	51.67	20	51.534	-22	44.63	2.3536	1.4915	15.09	19.67	22.74	14.85	-7.8	293.9
1981	2	22	0.0	2444657.5	20	54.020	-22	33.71	20	55.823	-22	26.52	2.3711	1.5182	15.19	19.74	23.69	15.18	-7.7	294.6
1981	2	24	0.0	2444659.5	20	58.204	-22	15.82	21	0.000	-22	8.49	2.3878	1.5446	15.28	19.80	24.66	15.51	-7.6	295.3
1981	2	26	0.0	2444661.5	21	2.280	-21	58.02	21	4.071	-21	50.56	2.4036	1.5706	15.37	19.86	25.66	15.84	-7.5	295.9
1981	2	28	0.0	2444663.5	21	6.253	-21	40.33	21	8.037	-21	32.74	2.4185	1.5964	15.45	19.92	26.67	16.17	-7.4	296.6
1981	3	2	0.0	2444665.5	21	10.126	-21	22.76	21	11.904	-21	15.06	2.4326	1.6219	15.53	19.98	27.71	16.51	-7.3	297.2
1981	3	4	0.0	2444667.5	21	13.901	-21	5.34	21	15.674	-20	57.52	2.4458	1.6472	15.61	20.03	28.76	16.84	-7.2	297.7
1981	3	6	0.0	2444669.5	21	17.582	-20	48.08	21	19.350	-20	40.15	2.4582	1.6721	15.69	20.08	29.84	17.17	-7.1	298.3
1981	3	8	0.0	2444671.5	21	21.172	-20	30.99	21	22.934	-20	22.96	2.4697	1.6968	15.76	20.14	30.94	17.50	-7.0	298.8

Table 5 (continued)

Ephemeris for Comet Encke (1980-1981)

1981	3	10	0.0	2444673.5	21	24.672	-20	14.09	21	26.429	-20	5.95	2.4804	1.7213	15.83	20.19	32.05	17.83	-6.9	299.4
1981	3	12	0.0	2444675.5	21	28.094	-19	57.39	21	29.836	-19	49.15	2.4903	1.7454	15.90	20.24	33.18	18.15	-6.8	299.9

THE ABOVE EPHEMERIS IS BASED ON THE FOLLOWING ECLIPTIC (1950.0) ORBITAL ELEMENTS.

YR	MN	DY	HR	J.D.	Q	E	SOMEGA	LOMEGA	I
1980	12	6	13.8	2444580.07610	0.3399411	0.8467578	185.97967	334.19764	11.94599

Table 6
Ephemeris for Comet Encke (1983-1984)

YR	MN	DY	HR	J.D.	R.A. 1960.0	DEC.	R.A. DATE	DEC.	DELTA	R	TMAG	NMAG	THETA	BETA	LAT	LONG
1983	10	1	0.0	2445608.5	0 5.772	12 4.18	0 7.505	12 15.44	1.5830	2.5740	16.60	19.67	169.49	4.07	6.4	6.4
1983	10	3	0.0	2445610.5	0 2.332	11 48.38	0 4.064	11 59.66	1.6682	2.5574	16.55	19.65	168.86	4.33	6.5	6.6
1983	10	5	0.0	2445612.5	23 58.858	11 31.78	0 0.587	11 43.06	1.5547	2.5407	16.51	19.63	167.60	4.85	6.5	6.9
1983	10	7	0.0	2445614.5	23 55.362	11 14.43	23 57.090	11 25.71	1.5426	2.5238	16.46	19.62	165.86	5.55	6.6	7.1
1983	10	9	0.0	2445616.5	23 51.860	10 56.42	23 53.585	11 7.69	1.5319	2.5067	16.42	19.61	163.79	6.39	6.6	7.4
1983	10	11	0.0	2445618.5	23 48.364	10 37.80	23 50.083	10 49.07	1.5225	2.4896	16.37	19.61	161.51	7.31	6.6	7.6
1983	10	13	0.0	2445620.5	23 44.890	10 18.68	23 46.612	10 29.94	1.5144	2.4723	16.33	19.62	159.08	8.29	6.7	7.9
1983	10	15	0.0	2445622.5	23 41.450	9 59.13	23 43.170	10 10.38	1.5076	2.4548	16.29	19.62	156.55	9.30	6.7	8.1
1983	10	17	0.0	2445624.5	23 38.057	9 39.25	23 39.777	9 50.49	1.5021	2.4372	16.25	19.63	153.96	10.34	6.8	8.4
1983	10	19	0.0	2445626.5	23 34.726	9 19.13	23 36.444	9 30.35	1.4978	2.4194	16.21	19.64	151.32	11.39	6.8	8.7
1983	10	21	0.0	2445628.5	23 31.467	8 58.85	23 33.184	9 10.06	1.4947	2.4015	16.18	19.65	148.66	12.45	6.9	8.9
1983	10	23	0.0	2445630.5	23 28.291	8 38.53	23 30.003	8 49.72	1.4928	2.3835	16.14	19.66	145.99	13.50	6.9	9.2
1983	10	25	0.0	2445632.5	23 25.211	8 18.23	23 26.927	8 29.40	1.4920	2.3653	16.11	19.67	143.31	14.55	7.0	9.5
1983	10	27	0.0	2445634.5	23 22.235	7 58.07	23 23.951	8 9.22	1.4922	2.3469	16.07	19.69	140.64	15.58	7.0	9.7
1983	10	29	0.0	2445636.5	23 19.374	7 38.11	23 21.089	7 49.24	1.4935	2.3284	16.04	19.70	137.97	16.60	7.1	10.0
1983	10	31	0.0	2445638.5	23 16.635	7 18.45	23 18.350	7 29.55	1.4957	2.3097	16.01	19.72	135.32	17.59	7.1	10.3
1983	11	2	0.0	2445640.5	23 14.026	6 59.16	23 15.741	7 10.25	1.4988	2.2909	15.98	19.74	132.69	18.57	7.1	10.6
1983	11	4	0.0	2445642.5	23 11.555	6 40.34	23 13.270	6 51.40	1.5027	2.2719	15.95	19.75	130.08	19.51	7.2	10.9
1983	11	6	0.0	2445644.5	23 9.227	6 22.04	23 10.943	6 33.08	1.5075	2.2527	15.92	19.77	127.50	20.43	7.3	11.2
1983	11	8	0.0	2445646.5	23 7.047	6 4.34	23 8.763	6 15.36	1.5129	2.2334	15.89	19.78	124.95	21.32	7.3	11.5
1983	11	10	0.0	2445648.5	23 5.019	5 47.30	23 6.735	5 58.30	1.5189	2.2139	15.86	19.80	122.43	22.18	7.4	11.8
1983	11	12	0.0	2445650.5	23 3.144	5 30.97	23 4.861	5 41.94	1.5255	2.1942	15.83	19.81	119.94	23.01	7.4	12.2
1983	11	14	0.0	2445652.5	23 1.425	5 15.38	23 3.142	5 26.34	1.5326	2.1744	15.80	19.83	117.49	23.81	7.5	12.5
1983	11	16	0.0	2445654.5	22 59.862	5 0.58	23 1.580	5 11.52	1.5402	2.1543	15.77	19.84	115.07	24.57	7.5	12.8
1983	11	18	0.0	2445656.5	22 58.455	4 46.60	23 0.174	4 57.52	1.5481	2.1341	15.74	19.85	112.69	25.30	7.6	13.2
1983	11	20	0.0	2445658.5	22 57.204	4 33.46	22 58.924	4 44.37	1.5563	2.1137	15.71	19.87	110.35	26.00	7.6	13.5
1983	11	22	0.0	2445660.5	22 56.109	4 21.18	22 57.829	4 32.08	1.5647	2.0931	15.68	19.88	108.04	26.66	7.7	13.9
1983	11	24	0.0	2445662.5	22 55.166	4 9.78	22 56.887	4 20.66	1.5734	2.0724	15.65	19.89	105.77	27.29	7.7	14.2
1983	11	26	0.0	2445664.5	22 54.377	3 59.26	22 56.098	4 10.13	1.5821	2.0514	15.62	19.89	103.54	27.89	7.8	14.6
1983	11	28	0.0	2445666.5	22 53.738	3 49.64	22 55.460	4 0.51	1.5910	2.0302	15.58	19.90	101.34	28.45	7.9	15.0
1983	11	30	0.0	2445668.5	22 53.247	3 40.92	22 54.971	3 51.78	1.5998	2.0089	15.55	19.90	99.18	28.99	7.9	15.3
1983	12	2	0.0	2445670.5	22 52.904	3 33.11	22 54.628	3 43.97	1.6086	1.9873	15.51	19.91	97.06	29.50	8.0	15.7
1983	12	4	0.0	2445672.5	22 52.706	3 26.22	22 54.430	3 37.08	1.6173	1.9656	15.48	19.91	94.97	29.97	8.0	16.1
1983	12	6	0.0	2445674.5	22 52.649	3 20.23	22 54.374	3 31.09	1.6259	1.9436	15.44	19.91	92.92	30.42	8.1	16.5
1983	12	8	0.0	2445676.5	22 52.732	3 15.16	22 54.458	3 26.02	1.6342	1.9214	15.40	19.91	90.90	30.84	8.2	17.0
1983	12	10	0.0	2445678.5	22 52.950	3 10.99	22 54.577	3 21.86	1.6423	1.8990	15.36	19.91	88.92	31.23	8.2	17.4
1983	12	12	0.0	2445680.5	22 53.301	3 7.72	22 55.028	3 18.60	1.6501	1.8764	15.32	19.90	86.98	31.60	8.3	17.8
1983	12	14	0.0	2445682.5	22 53.782	3 5.34	22 55.509	3 16.22	1.6576	1.8536	15.28	19.90	85.06	31.94	8.4	18.3
1983	12	16	0.0	2445684.5	22 54.388	3 3.82	22 56.115	3 14.71	1.6646	1.8305	15.23	19.89	83.19	32.26	8.4	18.7
1983	12	18	0.0	2445686.5	22 55.118	3 3.17	22 56.847	3 14.08	1.6712	1.8072	15.19	19.88	81.34	32.56	8.5	19.2
1983	12	20	0.0	2445688.5	22 55.968	3 3.37	22 57.597	3 14.29	1.6774	1.7837	15.14	19.87	79.53	32.84	8.6	19.7
1983	12	22	0.0	2445690.5	22 56.935	3 4.41	22 58.564	3 15.34	1.6830	1.7599	15.09	19.85	77.74	33.11	8.6	20.2
1983	12	24	0.0	2445692.5	22 58.018	3 6.27	22 59.747	3 17.22	1.6881	1.7359	15.03	19.84	75.99	33.35	8.7	20.7
1983	12	26	0.0	2445694.5	22 59.213	3 8.95	23 0.943	3 19.91	1.6926	1.7116	14.98	19.82	74.27	33.58	8.8	21.2
1983	12	28	0.0	2445696.5	23 0.519	3 12.43	23 2.249	3 23.42	1.6965	1.6871	14.92	19.80	72.58	33.79	8.9	21.8
1983	12	30	0.0	2445698.5	23 1.935	3 16.72	23 3.665	3 27.72	1.6998	1.6623	14.86	19.78	70.91	33.99	8.9	22.3
1984	1	1	0.0	2445700.5	23 3.457	3 21.79	23 5.188	3 32.82	1.7024	1.6372	14.80	19.75	69.28	34.18	9.0	22.9

Table 6 (continued)
Ephemeris for Comet Encke (1983–1984)

1984	1	3	0.0	2445702.5	23	5.085	3	27.65	23	6.816	3	38.70	1.7043	1.6119	14.73	19.72	67.67	34.35	9.1	23.5
1984	1	5	0.0	2445704.5	23	6.817	3	34.29	23	8.548	3	45.35	1.7054	1.5863	14.66	19.70	66.10	34.52	9.2	24.1
1984	1	7	0.0	2445706.5	23	8.651	3	41.68	23	10.382	3	52.77	1.7057	1.5604	14.59	19.67	64.55	34.68	9.3	24.8
1984	1	9	0.0	2445708.5	23	10.584	3	49.83	23	12.315	4	0.94	1.7053	1.5342	14.52	19.63	63.03	34.84	9.4	25.4
1984	1	11	0.0	2445710.5	23	12.617	3	58.72	23	14.349	4	9.85	1.7040	1.5077	14.44	19.60	61.54	34.99	9.4	26.1
1984	1	13	0.0	2445712.5	23	14.746	4	8.33	23	16.479	4	19.49	1.7018	1.4810	14.36	19.56	60.07	35.13	9.5	26.8
1984	1	15	0.0	2445714.5	23	16.973	4	18.67	23	18.706	4	29.85	1.6988	1.4539	14.28	19.52	58.63	35.28	9.6	27.5
1984	1	17	0.0	2445716.5	23	19.294	4	29.71	23	21.028	4	40.91	1.6948	1.4265	14.19	19.48	57.22	35.43	9.7	28.3
1984	1	19	0.0	2445718.5	23	21.711	4	41.45	23	23.445	4	52.67	1.6899	1.3987	14.10	19.44	55.84	35.59	9.8	29.1
1984	1	21	0.0	2445720.5	23	24.223	4	53.87	23	25.957	5	5.12	1.6841	1.3707	14.00	19.39	54.48	35.75	9.9	29.9
1984	1	23	0.0	2445722.5	23	26.830	5	6.98	23	28.565	5	18.24	1.6772	1.3423	13.90	19.34	53.15	35.92	10.0	30.8
1984	1	25	0.0	2445724.5	23	29.534	5	20.75	23	31.269	5	32.03	1.6694	1.3135	13.80	19.29	51.84	36.11	10.1	31.6
1984	1	27	0.0	2445726.5	23	32.334	5	35.19	23	34.070	5	46.49	1.6605	1.2844	13.69	19.23	50.57	36.31	10.2	32.6
1984	1	29	0.0	2445728.5	23	35.232	5	50.28	23	36.969	6	1.60	1.6505	1.2549	13.57	19.18	49.32	36.52	10.3	33.6
1984	1	31	0.0	2445730.5	23	38.228	6	6.02	23	39.967	6	17.36	1.6395	1.2251	13.46	19.12	48.09	36.76	10.4	34.6
1984	2	2	0.0	2445732.5	23	41.324	6	22.40	23	43.064	6	33.75	1.6273	1.1949	13.33	19.05	46.90	37.02	10.5	35.7
1984	2	4	0.0	2445734.5	23	44.521	6	39.39	23	46.262	6	50.76	1.6140	1.1642	13.20	18.99	45.73	37.32	10.6	36.8
1984	2	6	0.0	2445736.5	23	47.820	6	56.99	23	49.562	7	8.36	1.5995	1.1332	13.06	18.92	44.59	37.65	10.7	38.0
1984	2	8	0.0	2445738.5	23	51.223	7	15.16	23	52.965	7	26.54	1.5837	1.1018	12.92	18.85	43.47	38.02	10.8	39.3
1984	2	10	0.0	2445740.5	23	54.730	7	33.88	23	56.475	7	45.27	1.5667	1.0699	12.77	18.77	42.39	38.44	11.0	40.6
1984	2	12	0.0	2445742.5	23	58.345	7	53.13	0	0.092	8	4.53	1.5484	1.0376	12.61	18.70	41.33	38.92	11.1	42.1
1984	2	14	0.0	2445744.5	0	2.068	8	12.86	0	3.817	8	24.26	1.5288	1.0049	12.44	18.62	40.31	39.46	11.2	43.6
1984	2	16	0.0	2445746.5	0	5.902	8	33.03	0	7.654	8	44.42	1.5078	0.9718	12.27	18.53	39.31	40.08	11.3	45.2
1984	2	18	0.0	2445748.5	0	9.850	8	53.58	0	11.504	9	4.97	1.4854	0.9382	12.08	18.44	38.34	40.79	11.4	47.0
1984	2	20	0.0	2445750.5	0	13.912	9	14.46	0	15.669	9	25.83	1.4615	0.9041	11.89	18.35	37.39	41.60	11.5	48.8
1984	2	22	0.0	2445752.5	0	18.092	9	35.57	0	19.852	9	46.93	1.4361	0.8697	11.68	18.26	36.48	42.54	11.6	50.9
1984	2	24	0.0	2445754.5	0	22.390	9	56.81	0	24.153	10	8.16	1.4091	0.8348	11.46	18.16	35.58	43.61	11.7	53.1
1984	2	26	0.0	2445756.5	0	26.805	10	18.06	0	28.571	10	29.39	1.3805	0.7995	11.23	18.06	34.72	44.85	11.8	55.5
1984	2	28	0.0	2445758.5	0	31.335	10	39.14	0	33.105	10	50.44	1.3501	0.7637	10.98	17.96	33.88	46.29	11.9	58.1
1984	3	1	0.0	2445760.5	0	35.974	10	59.83	0	37.748	11	11.10	1.3178	0.7277	10.72	17.85	33.05	47.96	11.9	60.9
1984	3	3	0.0	2445762.5	0	40.712	11	19.84	0	42.490	11	31.06	1.2837	0.6913	10.44	17.74	32.24	49.92	11.9	64.1
1984	3	5	0.0	2445764.5	0	45.532	11	38.77	0	47.315	11	49.95	1.2475	0.6547	10.14	17.63	31.44	52.21	11.9	67.7
1984	3	7	0.0	2445766.5	0	50.408	11	56.12	0	52.195	12	7.25	1.2091	0.6180	9.82	17.52	30.64	54.92	11.8	71.6
1984	3	9	0.0	2445768.5	0	55.300	12	11.20	0	57.091	12	22.28	1.1685	0.5814	9.48	17.40	29.82	58.13	11.7	76.0
1984	3	11	0.0	2445770.5	1	0.146	12	23.11	1	1.941	12	34.12	1.1255	0.5451	9.12	17.30	28.96	61.96	11.4	81.1
1984	3	13	0.0	2445772.5	1	4.855	12	30.58	1	6.655	12	41.53	1.0801	0.5094	8.74	17.20	28.04	66.54	11.0	86.8
1984	3	15	0.0	2445774.5	1	9.293	12	31.94	1	11.097	12	42.84	1.0322	0.4748	8.33	17.11	27.01	72.07	10.4	93.4
1984	3	17	0.0	2445776.5	1	13.265	12	24.93	1	15.071	12	35.76	0.9820	0.4419	7.91	17.05	25.82	78.74	9.6	100.9
1984	3	19	0.0	2445778.5	1	16.496	12	6.55	1	18.303	12	17.33	0.9298	0.4116	7.49	17.02	24.38	86.80	8.4	109.5
1984	3	21	0.0	2445780.5	1	18.613	11	33.01	1	20.420	11	43.75	0.8764	0.3851	7.07	17.04	22.59	96.47	6.9	119.4
1984	3	23	0.0	2445782.5	1	19.154	10	39.87	1	20.957	10	50.61	0.8230	0.3636	6.68	17.12	20.31	107.90	4.9	130.5
1984	3	25	0.0	2445784.5	1	17.622	9	22.81	1	19.418	9	33.57	0.7716	0.3487	6.36	17.28	17.42	121.08	2.4	142.6
1984	3	27	0.0	2445786.5	1	13.623	7	39.06	1	15.410	7	49.90	0.7248	0.3415	6.14	17.54	13.84	135.65	-0.3	155.5
1984	3	29	0.0	2445788.5	1	7.053	5	29.50	1	8.829	5	40.44	0.6852	0.3429	6.03	17.88	9.65	150.77	-3.0	168.7
1984	3	31	0.0	2445790.5	0	58.242	2	59.99	1	0.007	3	11.05	0.6551	0.3525	6.05	18.25	5.45	164.39	-5.5	181.5
1984	4	2	0.0	2445792.5	0	47.906	0	20.66	0	49.562	0	31.84	0.6353	0.3697	6.19	18.39	4.49	167.77	-7.6	193.4
1984	4	4	0.0	2445794.5	0	36.938	- 2	17.06	0	38.685	- 2	5.77	0.6256	0.3929	6.42	18.18	8.57	157.70	-9.2	204.2
1984	4	6	0.0	2445796.5	0	26.145	- 4	43.72	0	27.893	- 4	32.35	0.6244	0.4208	6.72	17.97	13.66	145.84	-10.3	213.7

Table 6 (continued)
Ephemeris for Comet Encke (1983-1984)

1984	4	8	0.0	2445798.5	0 16.103	- 6 53.62	0 17.351	- 6 42.21	0.6299	0.4520	7.05	17.82	18.65	134.88	-11.1	222.1
1984	4	10	0.0	2445800.5	0 7.124	- 8 44.78	0 8.875	- 8 33.34	0.6403	0.4855	7.39	17.72	23.32	125.20	-11.5	229.3
1984	4	12	0.0	2445802.5	23 59.315	-10 17.78	0 1.070	-10 6.33	0.6539	0.5205	7.74	17.66	27.61	116.77	-11.8	235.7
1984	4	14	0.0	2445804.5	23 52.646	-11 34.55	23 54.407	-11 23.10	0.6695	0.5564	8.08	17.64	31.53	109.48	-11.9	241.2
1984	4	16	0.0	2445806.5	23 47.020	-12 37.53	23 48.785	-12 26.10	0.6861	0.5929	8.41	17.64	35.11	103.15	-11.9	246.0
1984	4	18	0.0	2445808.5	23 42.304	-13 29.14	23 44.074	-13 17.72	0.7031	0.6295	8.73	17.66	38.41	97.65	-11.9	250.3
1984	4	20	0.0	2445810.5	23 38.364	-14 11.55	23 40.139	-14 0.14	0.7199	0.6662	9.02	17.69	41.47	92.84	-11.8	254.1
1984	4	22	0.0	2445812.5	23 35.073	-14 46.59	23 36.851	-14 35.20	0.7362	0.7027	9.30	17.73	44.33	88.61	-11.6	257.5
1984	4	24	0.0	2445814.5	23 32.314	-15 15.81	23 34.095	-15 4.43	0.7519	0.7390	9.57	17.77	47.03	84.86	-11.5	260.6
1984	4	26	0.0	2445816.5	23 29.989	-15 40.45	23 31.774	-15 29.08	0.7666	0.7750	9.82	17.81	49.60	81.51	-11.3	263.4
1984	4	28	0.0	2445818.5	23 28.012	-16 1.52	23 29.799	-15 50.16	0.7805	0.8105	10.05	17.86	52.07	78.50	-11.1	265.9
1984	4	30	0.0	2445820.5	23 26.308	-16 19.84	23 28.093	-16 8.49	0.7933	0.8457	10.27	17.91	54.46	75.78	-10.9	268.2
1984	5	2	0.0	2445822.5	23 24.815	-16 36.07	23 26.603	-16 24.73	0.8050	0.8805	10.48	17.95	56.79	73.30	-10.7	270.3
1984	5	4	0.0	2445824.5	23 23.481	-16 50.74	23 25.275	-16 39.41	0.8158	0.9148	10.67	18.00	59.08	71.02	-10.6	272.3
1984	5	6	0.0	2445826.5	23 22.259	-17 4.31	23 24.056	-16 52.99	0.8255	0.9487	10.86	18.04	61.32	68.91	-10.4	274.1
1984	5	8	0.0	2445828.5	23 21.112	-17 17.13	23 22.911	-17 5.81	0.8342	0.9822	11.03	18.08	63.55	66.95	-10.2	275.8
1984	5	10	0.0	2445830.5	23 20.006	-17 29.49	23 21.806	-17 18.18	0.8420	1.0152	11.19	18.11	65.76	65.10	-10.0	277.4
1984	5	12	0.0	2445832.5	23 18.912	-17 41.65	23 20.715	-17 30.34	0.8488	1.0478	11.35	18.15	67.97	63.36	-9.9	278.9
1984	5	14	0.0	2445834.5	23 17.806	-17 53.80	23 19.610	-17 42.51	0.8548	1.0799	11.49	18.18	70.17	61.70	-9.7	280.3
1984	5	16	0.0	2445836.5	23 16.664	-18 6.14	23 18.470	-17 54.85	0.8599	1.1116	11.63	18.21	72.39	60.11	-9.5	281.6
1984	5	18	0.0	2445838.5	23 15.466	-18 18.80	23 17.273	-18 7.52	0.8642	1.1430	11.76	18.23	74.62	58.58	-9.4	282.8
1984	5	20	0.0	2445840.5	23 14.193	-18 31.92	23 16.004	-18 20.65	0.8678	1.1739	11.89	18.25	76.86	57.09	-9.2	284.0
1984	5	22	0.0	2445842.5	23 12.827	-18 45.62	23 14.641	-18 34.36	0.8707	1.2044	12.01	18.27	79.13	55.64	-9.1	285.1
1984	5	24	0.0	2445844.5	23 11.351	-18 59.99	23 13.167	-18 48.75	0.8729	1.2345	12.12	18.29	81.42	54.22	-8.9	286.2
1984	5	26	0.0	2445846.5	23 9.749	-19 15.11	23 11.569	-19 3.88	0.8746	1.2642	12.23	18.30	83.74	52.81	-8.8	287.2
1984	5	28	0.0	2445848.5	23 8.007	-19 31.05	23 9.829	-19 19.84	0.8757	1.2936	12.33	18.31	86.10	51.42	-8.6	288.1
1984	5	30	0.0	2445850.5	23 6.110	-19 47.87	23 7.935	-19 36.68	0.8764	1.3226	12.43	18.32	88.49	50.02	-8.5	289.1
1984	6	1	0.0	2445852.5	23 4.045	-20 5.59	23 5.875	-19 54.42	0.8767	1.3512	12.52	18.33	90.92	48.63	-8.4	289.9
1984	6	3	0.0	2445854.5	23 1.802	-20 24.24	23 3.635	-20 13.10	0.8767	1.3795	12.61	18.33	93.39	47.23	-8.3	290.8
1984	6	5	0.0	2445856.5	22 59.368	-20 43.81	23 1.206	-20 32.70	0.8764	1.4075	12.70	18.33	95.91	45.82	-8.1	291.6
1984	6	7	0.0	2445858.5	22 56.735	-21 4.31	22 58.573	-20 53.24	0.8760	1.4351	12.78	18.33	98.47	44.39	-8.0	292.3
1984	6	9	0.0	2445860.5	22 53.895	-21 25.70	22 55.743	-21 14.66	0.8755	1.4624	12.86	18.32	101.07	42.94	-7.9	293.1
1984	6	11	0.0	2445862.5	22 50.840	-21 47.94	22 52.694	-21 36.95	0.8749	1.4894	12.94	18.32	103.73	41.48	-7.8	293.8
1984	6	13	0.0	2445864.5	22 47.563	-22 10.98	22 49.424	-22 0.03	0.8745	1.5161	13.02	18.31	106.42	39.98	-7.7	294.5
1984	6	15	0.0	2445866.5	22 44.061	-22 34.74	22 45.923	-22 23.84	0.8741	1.5424	13.09	18.30	109.17	38.47	-7.6	295.2
1984	6	17	0.0	2445868.5	22 40.327	-22 59.15	22 42.202	-22 48.31	0.8740	1.5685	13.16	18.29	111.96	36.92	-7.5	295.8
1984	6	19	0.0	2445870.5	22 36.361	-23 24.09	22 38.243	-23 13.32	0.8741	1.5943	13.23	18.28	114.80	35.35	-7.4	296.4
1984	6	21	0.0	2445872.5	22 32.160	-23 49.47	22 34.051	-23 38.77	0.8747	1.6198	13.30	18.27	117.68	33.75	-7.3	297.0
1984	6	23	0.0	2445874.5	22 27.726	-24 15.13	22 29.625	-24 4.52	0.8757	1.6451	13.37	18.26	120.61	32.13	-7.2	297.6
1984	6	25	0.0	2445876.5	22 23.064	-24 40.93	22 24.973	-24 30.41	0.8772	1.6700	13.44	18.24	123.57	30.48	-7.1	298.2
1984	6	27	0.0	2445878.5	22 18.181	-25 6.70	22 20.100	-24 56.28	0.8794	1.6948	13.51	18.23	126.57	28.80	-7.0	298.7
1984	6	29	0.0	2445880.5	22 13.085	-25 32.26	22 15.015	-25 21.95	0.8823	1.7192	13.58	18.22	129.60	27.11	-6.9	299.3
1984	7	1	0.0	2445882.5	22 7.792	-25 57.42	22 9.733	-25 47.22	0.8859	1.7434	13.65	18.21	132.66	25.40	-6.8	299.8
1984	7	3	0.0	2445884.5	22 2.319	-26 21.98	22 4.271	-26 11.92	0.8905	1.7673	13.72	18.19	135.73	23.68	-6.7	300.3
1984	7	5	0.0	2445886.5	21 56.684	-26 45.76	21 58.649	-26 35.83	0.8960	1.7910	13.79	18.19	138.82	21.95	-6.6	300.8
1984	7	7	0.0	2445888.5	21 50.913	-27 8.55	21 52.889	-26 58.78	0.9025	1.8145	13.86	18.18	141.91	20.22	-6.6	301.2
1984	7	9	0.0	2445890.5	21 45.030	-27 30.19	21 47.013	-27 20.58	0.9100	1.8377	13.94	18.17	144.98	18.51	-6.5	301.7
1984	7	11	0.0	2445892.5	21 39.061	-27 50.52	21 41.062	-27 41.07	0.9187	1.8607	14.01	18.17	148.04	16.81	-6.4	302.2

Table 6 (continued)
Ephemeris for Comet Encke (1983-1984)

1984	7	13	0.0	2445894.5	21	33.036	-28	9.41	21	35.049	-28	0.13	0.9286	1.8835	14.09	18.17	151.05	15.14	-6.3	302.6
1984	7	15	0.0	2445896.5	21	26.983	-28	26.73	21	29.008	-28	17.64	0.9396	1.9060	14.17	18.17	154.01	13.52	-6.2	303.0
1984	7	17	0.0	2445898.5	21	20.933	-28	42.40	21	22.969	-28	33.50	0.9519	1.9284	14.24	18.18	156.88	11.94	-6.2	303.5
1984	7	19	0.0	2445900.5	21	14.914	-28	56.35	21	16.962	-28	47.64	0.9654	1.9505	14.33	18.19	159.64	10.45	-6.1	303.9
1984	7	21	0.0	2445902.5	21	8.958	-29	8.55	21	11.017	-29	0.04	0.9803	1.9724	14.41	18.20	162.22	9.05	-6.0	304.3
1984	7	23	0.0	2445904.5	21	3.091	-29	18.97	21	5.160	-29	10.66	0.9964	1.9941	14.49	18.22	164.55	7.80	-5.9	304.7
1984	7	25	0.0	2445906.5	20	57.342	-29	27.64	20	59.421	-29	19.53	1.0138	2.0156	14.57	18.25	166.52	6.75	-5.9	305.1
1984	7	27	0.0	2445908.5	20	51.735	-29	34.58	20	53.824	-29	26.68	1.0326	2.0369	14.66	18.29	167.97	5.97	-5.8	305.4
1984	7	29	0.0	2445910.5	20	46.295	-29	39.86	20	48.392	-29	32.15	1.0526	2.0580	14.75	18.34	168.72	5.54	-5.7	305.8
1984	7	31	0.0	2445912.5	20	41.042	-29	43.53	20	43.146	-29	36.03	1.0740	2.0789	14.83	18.41	168.67	5.51	-5.7	306.2
1984	8	2	0.0	2445914.5	20	35.994	-29	45.70	20	38.105	-29	38.39	1.0966	2.0996	14.92	18.49	167.86	5.83	-5.6	306.5
1984	8	4	0.0	2445916.5	20	31.165	-29	46.46	20	33.284	-29	39.34	1.1204	2.1201	15.01	18.57	166.46	6.43	-5.5	306.9
1984	8	6	0.0	2445918.5	20	26.568	-29	45.92	20	28.692	-29	38.98	1.1455	2.1404	15.10	18.66	164.65	7.21	-5.5	307.2
1984	8	8	0.0	2445920.5	20	22.210	-29	44.19	20	24.339	-29	37.42	1.1717	2.1606	15.19	18.76	162.59	8.07	-5.4	307.5
1984	8	10	0.0	2445922.5	20	18.096	-29	41.38	20	20.229	-29	34.79	1.1991	2.1806	15.28	18.86	160.38	8.98	-5.4	307.9
1984	8	12	0.0	2445924.5	20	14.230	-29	37.61	20	16.365	-29	31.18	1.2276	2.2004	15.37	18.95	158.09	9.90	-5.3	308.2
1984	8	14	0.0	2445926.5	20	10.611	-29	32.99	20	12.750	-29	26.71	1.2571	2.2200	15.46	19.05	155.75	10.80	-5.2	308.5
1984	8	16	0.0	2445928.5	20	7.238	-29	27.62	20	9.380	-29	21.48	1.2877	2.2395	15.55	19.15	153.39	11.68	-5.2	308.8
1984	8	18	0.0	2445930.5	20	4.110	-29	21.59	20	6.254	-29	15.58	1.3193	2.2587	15.64	19.25	151.03	12.53	-5.1	309.1
1984	8	20	0.0	2445932.5	20	1.223	-29	14.98	20	3.369	-29	9.10	1.3519	2.2779	15.73	19.34	148.69	13.35	-5.1	309.4
1984	8	22	0.0	2445934.5	19	58.572	-29	7.89	20	0.713	-29	2.12	1.3864	2.2968	15.82	19.44	146.36	14.12	-5.0	309.7
1984	8	24	0.0	2445936.5	19	56.152	-29	0.38	19	58.299	-28	54.72	1.4197	2.3156	15.91	19.53	144.06	14.85	-4.9	310.0
1984	8	26	0.0	2445938.5	19	53.956	-28	52.53	19	56.103	-28	46.96	1.4550	2.3342	16.00	19.62	141.78	15.54	-4.9	310.3
1984	8	28	0.0	2445940.5	19	51.979	-28	44.38	19	54.126	-28	38.89	1.4910	2.3527	16.08	19.71	139.54	16.18	-4.8	310.6
1984	8	30	0.0	2445942.5	19	50.214	-28	35.98	19	52.361	-28	30.68	1.5278	2.3710	16.17	19.80	137.32	16.78	-4.8	310.8
1984	9	1	0.0	2445944.5	19	48.652	-28	27.40	19	50.799	-28	22.07	1.5653	2.3892	16.26	19.88	135.14	17.33	-4.7	311.1

THE ABOVE EPHEMERIS IS BASED ON THE FOLLOWING ECLIPTIC (1950.0) ORBITAL ELEMENTS.

YR	MN	DY	HR	J.D.	Q	E	SOMEGA	LOMEGA	I
1984	3	27	16.5	2445787.18721	0.3410024	0.8463305	185.99329	334.18436	11.92738

Although the 1977 apparition of comet Encke is a very poor one for observing, the ephemeris is included in the hope that a few astrometric observations will be successful.

V. STATISTICAL ERROR ANALYSIS FOR COMET ENCKE (1980)

The ORAN program (Hatch and Goad, 1973), developed by Wolf Research Corporation, was employed in the present error analysis of comet Encke. The program was modified to include the nongravitational forces appropriate for comet Encke. Planetary perturbations were taken into account and the partial derivatives (elements of the state transition matrices), relating the adjusted and unadjusted parameters at a time t to their initial conditions, were determined by numerically integrating their second derivatives. These variational equations were numerically integrated along with the equations of motion.

Marsden and Sekanina (1974) have shown that five apparitions of comet Encke can be linked before the secular decrease in the nongravitational parameters begins to degrade the residuals. For the present analysis, the 5 returns to perihelion (1967-1980) are represented by forty actual observations from August 2, 1967 through October 24, 1973 and by 28 additional, postulated observations from October 24, 1973 through November 16, 1980. One observation was processed at each of the 1978 and 1979 opposition dates and the 1980 recovery of the comet was assumed to occur on July 9. The postulated observation schedule was determined after considering the relative sun-earth-comet geometries, the available hours of dark observing time as well as the apparent nuclear and total magnitudes for various dates.

The error analysis was initialized in 1967 by a state vector and appropriate values for the nongravitational parameters. The initial a priori 8×8 covariance matrix was essentially infinite. Each set of observations was batch processed and the updated covariance was propagated forward in time via the state transition matrix to the date of each observation. The time history of the comet's error ellipsoid is presented in Table 7. The first column represents the dates on which one ground based observation was taken. The next six columns represent the 1-σ position errors (km) for the radial sun-comet direction $(\hat{r})$, the direction normal to the comet's orbital plane $(\hat{n})$, and the transverse direction defined by the cross product of the first two unit vectors $(\hat{T} = \hat{n} \times \hat{r})$. The columns headed by Δ, r and θ represent the earth-comet distance in AU, the Sun-comet distance in AU and the Sun-Earth-comet angle in degrees. The a priori errors represent the forward propagation of the covariance matrix obtained by processing all observations from 1967-1979. Columns 5, 6, and 7 reflect the effect of each 1980 observation on the comet's error ellipsoid. The final ground based observation on November 16 reduces the σ_r, σ_n and σ_T components to 416, 249 and 359 km. In the absence of further observations, the error components evolve dynamically; their magnitudes at any given time are due primarily to the comet's position in its orbit. In the absence of observations, the radial a priori error component will generally reach a maximum value when the comet's radial velocity reaches a maximum. This will occur when the comet's true anomaly is $\pm 90^{\circ}$. For the 1980 apparition of comet Encke, these two points correspond to November 15 and December 27, 1980. In a similar fashion, the comet's along track position error will generally reach a maximum value when the along track velocity is largest - at perihelion. For the 1980 apparition of comet Encke, perihelion (and the largest, along track, a priori, position error) occur on December 6.

Excluding the 1978 and 1979 opposition observations has a negligible effect upon the final intercept errors. However, by taking 1980 observations at 5-day intervals between July 9 and November 16, the errors on December 6th are reduced to 155, 186 and 660 km $(\sigma_r, \sigma_n, \sigma_T)$. These results underscore the fact that while observations made during past apparitions define the mean motion and the nongravitational parameters, it is the 1980 observations that contribute most strongly to the reduction of comet Encke's ephemeris uncertainty.

Table 7
Error Ellipse Components for Comet Encke (1980)

Date 1980-81	A priori errors* (in km)			1980 observations Processed** (in km)						
	σ_r	σ_n	σ_T	σ_r	σ_n	σ_T	Δ (a.u.)	r	θ (deg.)	Comments
July 9	4168	2130	3239	3352	1926	2471	2.43	2.33	72	Comet recovered
19	4338	2084	3275	2917	1737	2012	2.21	2.23	78	
29	4521	2036	3327	2572	1567	1683	1.98	2.13	84	
Aug. 8	4718	1985	3399	2271	1406	1426	1.76	2.03	90	
18	4933	1936	3494	1992	1249	1213	1.53	1.92	96	
28	5169	1894	3617	1644	1146	1026	1.31	1.81	101	
Sept. 7	5429	1876	3769	1469	945	836	1.10	1.69	107	
17	5717	1921	3952	1217	799	710	0.89	1.56	111	
27	6040	2117	4146	968	658	564	0.69	1.43	114	
Oct. 7	6403	2604	4301	724	524	427	0.51	1.28	112	
17	6811	3480	4347	504	400	313	0.36	1.13	103	
27	7258	4612	4407	387	308	264	0.28	0.97	77	
Nov. 6	7699	5595	5229	391	269	273	0.32	0.80	45	true anomaly = -90° on Nov. 15
16	7893	5683	8023	416	249	359	0.47	0.62	29	last comet observation
26	6628	4481	12910	401	234	579	0.70	0.44	23	
Dec. 6	399	3477	16833	171	243	874	1.00	0.34	20	
16	6663	3445	13010	315	289	827	1.30	0.42	15	
26	7880	3452	8789	418	359	688	1.52	0.60	11	true anomaly = +90° on Dec. 27
Jan. 5	7627	2946	6527	433	412	632	1.73	0.78	10	
15	7143	2150	5388	426	445	642	1.90	0.95	11	
25	6663	1432	4706	414	481	677	2.05	1.11	12	

*A priori, one-sigma errors (km) in the radial, normal and transverse directions. Last observation processed was mid-September, 1979.

**Evolution of one-sigma errors (km) if one ground based observation is processed at 10 day intervals from July 9 to November 16. Measurement noise 3 arc seconds.

The importance of the 1980 observations is due primarily to the proximity of comet Encke and the earth during October and November, 1980; for a certain angular measurement error, the linear error decreases as the mutual distance decreases.

The present error analysis of comet Encke assumes a $1\text{-}\sigma$ measurement noise of 3 arc seconds for both the right ascension and declination. This value is primarily due to the deviations of the comet's center of mass from the observed center of light. The 3 arc second value is consistent with the mean residuals obtained for various orbit determinations for past apparitions of comet Encke. Due to comet Encke's relatively high nuclear activity, the appropriate noise value is somewhat higher than for most other short period comets. The measurement noise for each observation is the same value, and the measurements themselves are assumed to be uncorrelated. This being the case, the only nonzero elements of the weighting matrix (W) are equal in value and aligned on the principal diagonal. If F denotes the conditional equation matrix, the normal matrix F^TWF can be reduced to $1/\sigma^2\ (F^TF)$ and the simplified covariance matrix becomes $\sigma^2\ (F^TF)^{-1}$. Thus the covariance matrix is linear with respect to measurement noise. For example, although the current analysis has been undertaken using a measurement noise of $\sigma = 3$ arc seconds, one only has to multiply the error component entries in Table 7 by 2/3 to obtain the results for $\sigma = 2$ arc seconds.

From Figure 3 it becomes clear why the 1980 apparition of comet Encke is such a favorable one for a space probe mission opportunity. The recovery of comet Encke on 1980 July 9 (position 1 in Figure 3) seems easily attainable since the Sun-Earth-comet angle is 72 degrees, a fact that insures that several hours of dark observing time are available to northern hemisphere observatories. The aphelic opposition observation (Roemer, 1972) in mid-August, 1972, underscores the facility with which this comet can be observed if the observing geometry is favorable. Even more important than its early recovery oppor-

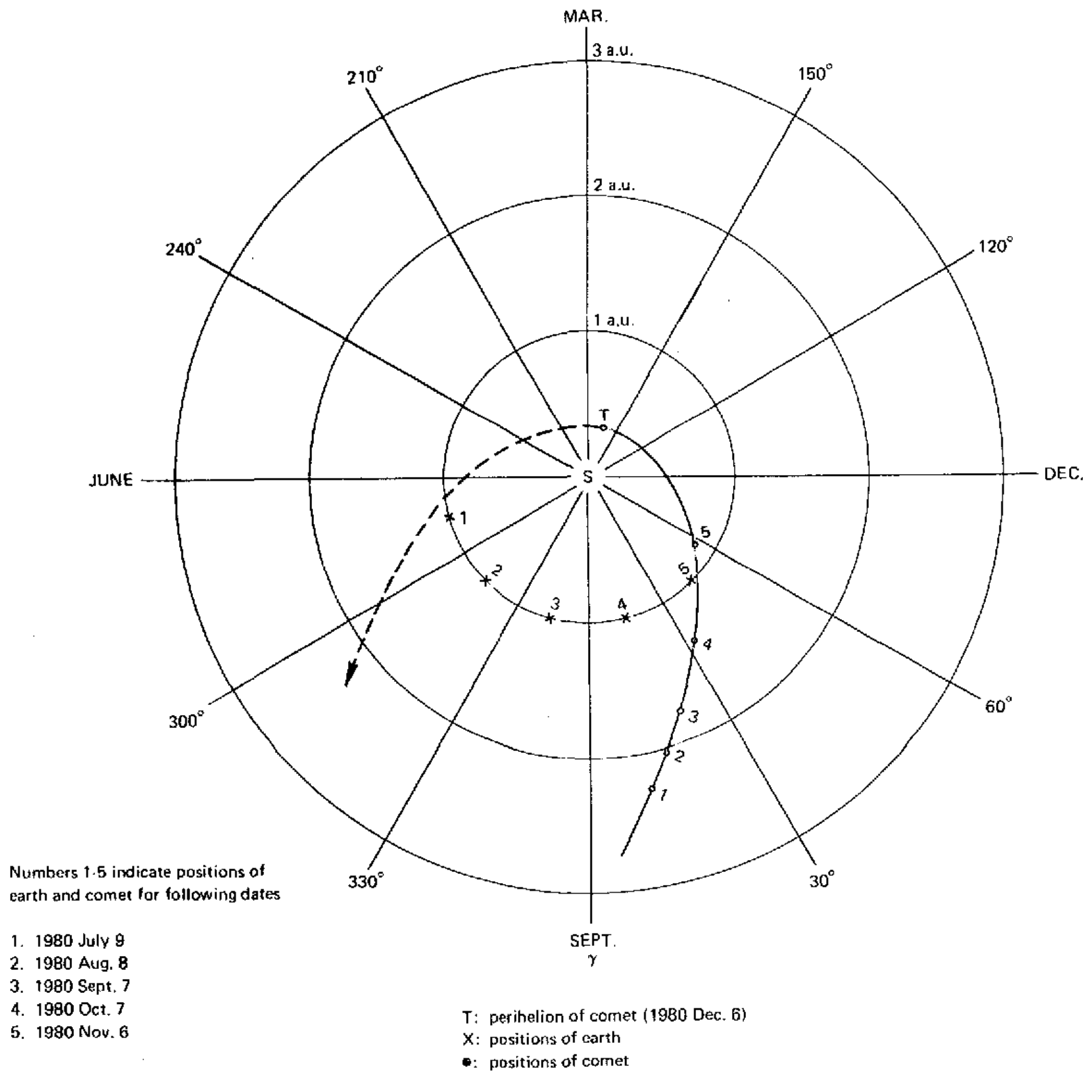


Figure 3. Earth-Comet Encke Relative Geometry in 1980.

tunity, is the excellent Earth-comet relative geometry in 1980. From the first observation (1980 July 9) to the last (1980 November 16) the geocentric longitude of the comet changes by nearly 180°. In addition, the geocentric distance of the comet becomes less than 0.3 a.u. toward the end of October, 1980. The large change in the geocentric longitude of the comet coupled with the proximity of the Earth and comet in October and November allow an excellent orbital refinement in 1980. This refinement is demonstrated by the substantial improvement in the cometary position errors effected by taking observations at 5 day intervals in 1980 rather than the 10 day intervals used in Table 7.

VI. CHECKS UPON STATISTICAL ERROR ANALYSIS FOR COMET ENCKE (1980)

The statistical error analysis outlined in the preceeding section was based upon simulated or hypothesized observations. Each observation was assigned a measurement noise of 3 arc seconds. While this measurement error, due largely to deviations between the comet's center of mass and its center of light, is the major error source, other neglected error sources are undoubtedly present. In an effort to check the statistical results, it is prudent to analyze results obtained using actual observations of comet Encke. Tables 2 and 3 present results obtained by processing past observations.

As explained in Section IV, ΔT is defined as the required correction to the comet's predicted perihelion passage time. The mean value for ΔT in Table 2 and its standard deviation is $\bar{\Delta}T = 0.00423 \pm 0.00094$ day. We can take $\bar{\Delta}T$ as an approximate upper limit to the a priori uncertainty in the transverse position error at perihelion. The comet's velocity at perihelion is approximately 6×10^6 km/day so that, at perihelion, $\bar{\Delta}T$ corresponds to a linear, transverse, position error of 25,380 km. However, the majority of this error is due to the unmodeled secular decrease in the transverse non-gravitational acceleration. An empirical ΔT correction can be added to the predicted time of perihelion passage to greatly reduce this error so that the standard deviation of $\bar{\Delta}T$ can be utilized as an approximate lower bound to the a priori, transverse position error at perihelion. At perihelion, this standard deviation (0.00094 day) corresponds to an approximate linear, transverse position error of 5,640 km. In a sense, the upper and lower limits on σ_T at perihelion are "observed" because they are based upon past prediction accuracies of comet Encke's times of perihelion passage (Table 2). From Table 7, the statistical, a priori, transverse, position error at perihelion (1980 December 6) is 16,833 km, a result that is bounded by the aforementioned "observed" upper and lower limits.

Unlike the ΔT corrections, the corrections (Δq) required to bring predicted perihelion distances in line with the observed perihelion distances for comet Encke are not predictable. However an estimate of the "observed" upper and lower limit can be determined from the maximum and minimum values of Δq (determined from Table 3). These values are $(8.9\text{-}0.6) \times 10^{-6}$ a.u or 1335-90 km. These "observed" errors bound the statistical, a priori radial, position error at perihelion (399 km from Table 7).

From the statistical error analysis, the radial and transverse position errors after all 1980 observations have been processed are $\sigma_r = 171$ km and $\sigma_T = 874$ km for 1980 December 6 (see Table 7). These position errors correspond to an error in perihelion distance of 1.1×10^{-6} a.u. and an error in perihelion passage time of 1.5×10^{-4} day. These results are compatible with the standard deviations associated with the differential corrections to the perihelion distance and perihelion passage time. For example, the orbital solution over the 1961-1973 observations (Table 1, orbit #5) yields a standard deviation of 0.94×10^{-6} a.u. and 1.07×10^{-4} day for the differential corrections to the perihelion distance and perihelion passage time.

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